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Roadside floristic patterns and revegetation by using native plants in Terra Nova National Park, Newfoundland, Canada

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NOTE TO USERS

Roadside Floristic Patterns and Revegetation by Using Native Plants in Terra Nova National Park, Newfoundland, Canada

By

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Abstract

This thesis reports on a study of roadside floristic patterns and revegetation (cultural methods) of newly constructed roadsides by using native plants along Trans Canada Highway (TCH) in Terra Nova National Park (TNNP), Newfoundland.

Recognizing the need for developing natural and self-sustained roadside vegetation cover to mitigate road effects, the first chapter of this thesis examines two aspects of the roadside floristic patterns: a) the nature of plant community composition across the roadside habitats with respect to microtopographic features, substrate properties and maintenance disturbances and b) the nature of above and below ground architectural characteristics and biomass allocation patterns of selected dominant plants across roadside microhabitats. The combined knowledge about floristic patterns and autecological attributes of roadside plants should help in selecting desirable native plants for roadside revegetation in order to mitigate road effects. The vegetation survey and soil sampling were conducted across the right-of-way along 10-15 years old section of the Trans Canada Highway (TCH) in Terra Nova National Park (TNNP), Newfoundland. The Multi-response Permutation Procedure (MRPP) confirmed the zonation of plant community across the right-of-way by distinguishing four plant communities occurring on four roadside microhabitats, such as shoulder, side slope, ditch and back slope. The Canonical Correspondence Analysis (CCA) showed that the composition of roadside plant communities in different microhabitats was related to soil moisture content, bulk density, organic, matter depth and pH. A number of indicator plants, determined by Indicator Species Analysis (ISA), were abundant and frequent in their respective microhabitats, indicating the preferential dominance of those plants to particular sets of environmental conditions The root-shoot analysis of selected dominant plants across the roadside habitat found that plants of a particular microhabitat had similar above and below ground architectural characteristics and biomass allocation patterns. It is concluded from this study that underlying substrate properties of roadside microhabitats play significant role on roadside plant community composition. It is also concluded that plants of a particular microhabitat have similar patterns of life history attributes enabling them to colonize and dominate in their respective microhabitats.

The second chapter of the thesis explores the use of selected planting materials and cultural methods for revegetation of newly constructed roadsides by using native plants. The objectives of this study were a) to compare the type of planting materials, such as seeds and transplants of native plants and b) to compare cultural treatments (stratification and mulching) on seed germination and transplant establishment. Experiments were conducted in greenhouse and in field conditions to observe the effects of stratification and mulching on germination of selected native plants respectively. Germination experiment was conducted with seeds of six native plants, of which four species, such as sheep laurel (*Kalmia angustifolia* Wang.), wild iris (*Iris versicolor* L.), soft rush (*Juncus effusus* L.) and cotton grass (*Eriophorum vaginatum* L.) germinated successfully, after one week of stratification (chilling and hydration at 0^0 C) under greenhouse conditions. However, only *I. versicolor* germinated successfully under field conditions. The organic matter mulch significantly increased germination and growth of *I. versicolor* under field conditions. Another field experiment was also conducted in newly constructed roadsides to observe the effect of hay-mat and organic matter mulching on survival and growth of transplanted seedlings and stem cuttings. Transplanted seedlings of *I. versicolor* and *Carex* sp. survived and grew better than the stem cuttings of black crowberry (*Empetrum nigrum* L.) and common juniper (*Juniperus communis* L.) without mulching treatment. Mulching did not enhance the survival and growth of transplanted seedlings of *I. versicolor* and *Carex* sp. However, mulching significantly enhanced survival and growth of *E. nigrum* and *J. communis* stem cuttings, 15 months after transplanting. Transplanted stem cuttings of *E. nigrum* survived and grew significantly better than that of *J. communis.* The greenhouse germination experiment and field trial by seeding suggests that proper stratification before seeding enhances seed germination of some native plants. Revegetation trial using transplants suggests that both seedlings and stem cuttings of native plants can be used as planting materials for roadside revegetation. Transplants revegetation trial also suggests that better survival and growth of vegetative cuttings can be achieved by hay-mat mulching.

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General Introduction

Road corridors are conspicuous artificial structures on the natural landscape that evolved from foot trails to complex highway systems. Road corridors are becoming a focus of ecological research because of their distinctive structure, function and impact on the surrounding ecosystems. Foreman and Alexander (1998) defined road corridors as pavement plus maintained roadsides and parallel vegetated strips along the roadside that extend up to the end of the right-of-way usually terminated by forest, lake, agricultural or other natural boundaries. Ecological impact of road systems is much wider than the width of road corridor (Foreman and Deblinger 2000). Many current ecological issues, such as habitat fragmentation, invasion of exotic species, soil erosion, edge effects and pollution are directly or indirectly related to road networks in the natural landscape (Forman and Alexander 1998; Forman and Deblinger 2000; Saunders et al. 1993; Trombulak and Frissel 2000; Parendes and Jones 2000). The road construction is inevitable due the need of socio-economic development; however, the mitigation of road effects has become a matter of serious concern.

Roadside restoration in the strict sense is neither possible nor desirable, since it implies a full return to a prior structure and functions of the disturbed habitat (National Research Council 1992). However, soil erosion control, traffic visibility, aesthetic value maintenance and reduction of exotic plant invasion are major concerns of roadside restoration. In this regard, establishment of a natural and self-sustained vegetation cover in order to mitigate road effects is considered as a main priority to both ecologists and road engineers. Currently, as a standard practice, road engineers often provide a grass cover by hydro-seeding immediately after road construction in order to reduce soil erosion. However, a broader ecological consideration in selecting plants for hydro-seeding has not been a priority to the road engineers (Andres and Jobra 2000).

The establishment of natural and self-sustained vegetation cover to meet roadside restoration goals requires sound knowledge, not only on natural plant colonization patterns along roadsides, but also on autecological attributes of the colonizing species. The autecological attributes of roadside plants, especially their regeneration strategies, above and below ground spread and biomass allocation patterns can be useful in selecting

candidate species for roadside revegetation. The knowledge about roadside plant colonization patterns and autecological attributes will help selecting suitable native plants that have potential to meet roadside restoration objectives. Several authors have described roadside plant communities but their study objectives were not related to the roadside restoration to mitigate road effects (Lausi and Nimis 1985; Ullman et al. 1995; Olander et al. 1998; Cilliers and Breadenkamp 2000). These studies recognized zonation of plant community across the road corridor with specific biophysical characteristics and floristic composition. They reported that soil moisture, organic matter content, bulk density, pH and light regime significantly change within the narrow width of the road corridor, affecting plant community composition. As these studies recognized vegetation pattern relation to environmental conditions, we expect that some plants of a particular roadside community may have similar autecological attributes that enable them to colonize in their respective community. We also expect that some of the species may have autecological attributes to meet the roadside restoration objectives. However, very little information is available on this aspect of roadside plants to initiate restoration activities by establishing a natural and self-sustained vegetation cover.

The autecological attributes of the naturally colonizing dominant plants along roadsides can be useful in selecting suitable native plants that have high potential to survive and regenerate on roadsides and reduce soil erosion. Their low stature can ensure traffic visibility and some of them have tolerance to automobile exhaust and de-icing salts (Mallik 2000). Establishment of native vegetation cover in the newly constructed roadside habitats may reduce the invasion of exotic species and soil erosion (Forman and Alexander 1998). Native species are important in conservation point of view, as they can maintain natural plant diversity (Knops et al. 1995). Some native species may have allelopathic effects on invasive plants that can reduce the cost for removing undesirable plants from roadside habitats (Mallik 1987, 2000). Evergreen leaves and colorful flowers of some native plants along roadsides can improve aesthetic value of roadsides. Knowledge on morphological features and regeneration strategies of plants with respect substrate properties would be useful in selecting suitable native plants for roadside revegetation.

The first chapter of this thesis is based upon the hypothesis that there is a zonation of plant community across the roadside microhabitats with respect to microtopographic features, substrate properties and maintenance disturbances. It was also hypothesized that dominant species of a particular plant community across roadside microhabitats have similar above and below ground architectural characteristics and biomass allocation patterns that enable them to establish in their respective microhabitats. Combined knowledge of these two aspects should help in selecting desirable, native plants for roadside revegetation in order to mitigate road effects. The following questions were addressed in the first chapter:

1) Is there any floristic difference across the roadside microhabitats with respect to roadside microtopography, substrate property and maintenance disturbance?
2) Do the differences in above and below ground architectural characteristics and biomass allocation patterns of the dominant plant influence their colonization and establishment in their respective microhabitats?
3) Which commonly occurring roadside native plants have the desirable above and below ground attributes for fulfilling the goals of roadside restoration?

Recently, innovative cultural methods for the revegetation of newly constructed roadsides by native plants are gaining popularity. Revegetation by seeding may be an effective method despite the biological limitations of native seeds and abiotic limitations of substrates (DeLeo 1999). By contrast, revegetation of roadsides with transplants, such as seedlings or vegetative cuttings may also be effective (Paschke et al. 2000; Fattorini 2001). Breaking seed dormancy can be a useful cultural technique to enhance seed germination. In addition, manipulations of inhospitable substrates by mulching with hay-mat and organic matter may improve the soil biophysical conditions for successful seed germination of native plants. Mulching treatments may also enhance the survival and growth of transplanted seedlings and vegetative cuttings (Smika and Unger 1986; Ji and Unger 2001). The second chapter of this thesis aims to examine several cultural methods for the revegetation of newly constructed roadside habitats. The following questions were addressed in the second chapter:

1. What planting materials (seed, seedling and vegetative cutting) are suitable for roadside revegetation?
2. Do stratification and mulching treatments enhance seed germination of native plants along newly constructed roadsides?
3. Do mulching treatments enhance the establishment and growth of transplanted seedlings and vegetative cuttings along newly constructed roadsides?

Chapter 1: Floristic zonation along roadsides: the role of microtopography, substrate properties and maintenance disturbances

Introduction

The road corridor, created on the terrestrial habitat has become a conspicuous feature in the landscape. The structure and function of the existing ecosystems have been significantly affected by the road corridor due to habitat fragmentation, alteration of hydrology, increased pollution, soil erosion and invasion of exotic species (Saunders et al. 1991; Forman and Alexander 1998; Forman and Deblinger 2000; Trombulak and Frissel 2000; Parendes and Jones 2000). Several studies have determined road effects on the surrounding ecosystems (Forman and Alexander 1998). However, a little is known about the ecology of the road corridor itself, as an artificial habitat that supports specialized biota and exchanges matter and energy with other ecosystems (Lugo and Gucinski 2000).

Road corridor is an artificial habitat that has biophysical properties totally different from the surrounding natural habitats (Diamondback 1990; Bennet 1991; Noss and Cooperrider 1994; Angold 1997). Forman and Alexander (1998) defined road corridors as pavement plus maintained roadsides and parallel vegetated strips along the roadside that extend up to the end of the right-of-way usually terminated by forest, lake, agricultural or other natural boundaries. Within road corridors, there is a distinct zonation of microhabitats, such as shoulder, side slope, ditch and back slope with specific biophysical characteristics and floristic composition (Lausi and Nimis 1985; Heindl and Ullman 1991; Ullman et al. 1995; Cilliers and Breadenkamp 2000). Soil moisture, organic matter content, bulk density, pH and light regime significantly change within the narrow width of the road corridor (Nancy et al. 1997; Cilliers and Breadenkamp 2000). Plant community composition, species diversity and distribution across the road corridor also change with the allogenic and biogenic heterogeneities of the habitat (Nancy et al. 1997; Olander et al. 1998).

Substrate properties, maintenance activities and pollution from automobile exhausts play a significant role in the floristic differences across the roadside habitats. Microtopographic variations resulting from road construction create micro-site

heterogeneities along roadsides (Whittaker and Levin 1977; Beatty 1984). Materials used for road construction, surface runoff from the pavement and soil compaction due to slope stabilization and traffic movement also affect roadside biophysical properties (Small and McCarthy 2002). Application of de-icing salt, a common road maintenance practice during wintertime in the temperate region, significantly affects the roadside plant communities (Scott and Davison 1982; Loenen et al. 1985; Thompson and Rutter 1986). Roadside maintenance activities for traffic visibility, such as brushwood cutting and herbicide application also affect species composition (Parr and Way 1984, 1988). Automobile emissions in the form of nitrogen oxides and heavy metals (i.e. lead particulates) are well known pollutants affecting roadside plant communities (Haqus and Hameed 1986; Spencer and Port 1988).

The dynamics of roadside vegetation are driven by the availability of plant propagules, their regenerative strategies, stress tolerating properties and response to competition and herbivory (Grubb 1977; Horn 1981; Werner 1976; Connell and Slatyer 1977; Bazzaz 1979; Grime 1979; Huston and Smith 1987; Tilman 1985, 1988). Early flowering, large number of viable seeds, long distance dispersal mechanisms, successful germination, and vegetative reproduction are some of the special life history strategies often enable plants to colonize in severely stressed and disturbed habitats (Baker 1965, 1972; Howe and Smallwood 1982; Green 1983; Bazzaz 1986; Primack and Miao 1992; Rejmanek and Richardson 1996; Parendes and Jones 2000).

Interactions between plant life history strategies and disturbance-stress continuum influence plant colonization and community composition in severely disturbed habitats, such as roadsides (Grime 1979; Tilman 1988; Halpern 1989; Hobbs and Huenneke 1992; Parendes and Jones 2000). Many ecologists hypothetically and empirically connected plant life history strategies with allogenic factors (MacArther and Wilson 1967; Harper and Ogden 1970; Gadgil and Solbrig 1972; Abramson and Gadgil 1973; McNaughton 1975; Raynal and Bazzaz 1975; Stearns 1977; Hickman 1977; Grime 1977, 1979; Hart 1980; Tilman 1985, 1988). Plant community composition based upon their life history strategies in response to environmental factors has also been studied in naturally and artificially disturbed habitats (Newell and Tramer 1978; Pickett and Bazzaz 1978; Givnish 1982; Menges and Waller 1983; McInyre et al. 1995). However, a little is known

about the interaction of plant life history strategies with roadside substrate properties and maintenance disturbance for organizing roadside plant communities.

Biomass allocation is a common plant life history strategy that indicates energy allocation patterns to different plant components in response to stress and disturbance (Chemielewski and Ringius 1987). The architectural characteristics of individual component of a given plant may depend on biomass allocation patterns in response to environmental factors (Mallik and Rashid 1993). The above and below ground architectural characteristics and biomass allocation strategies influence plants colonization and establishment in different environmental conditions (Sausa 1984; Gleeson and Tilman 1990). Soil properties and disturbance patterns often affect the above and below ground biomass allocation patterns and hence affect plant morphological attributes to ensure their regeneration and establishment (Cole and Holch 1941; Weaver and Darland 1949a; Grime 1979; Parish and Bazzaz 1982). However, very little is known about community organization of roadside plants in the light of their architectural characteristics and biomass allocation patterns.

This study was conducted based upon the hypothesis that distinct zonation of plant communities exists along roadside habitats with respect to microtopography, substrate properties and maintenance disturbances. It was also hypothesized that dominant plants of a particular community across roadside microhabitats have similar above and below ground architectural characteristics and biomass allocation patterns that enable them to establish in their respective microhabitats. The objectives of this study were 1) to examine the naturally occurring floristic patterns along roadside habitats with respect to microhabitat types, substrate properties and maintenance disturbances, and 2) to examine the above and below ground plant architectural characteristics and biomass allocation patterns of dominant plants that may enable them to colonize and establish in their respective microhabitats. Combined knowledge of these two aspects should help in selecting desirable native plants for roadside revegetation in order to meet roadside restoration objectives.

Materials and Methods

Study area

The study was conducted in Terra Nova National Park (TNNP), Newfoundland located at 48^0 30′ N latitude and 50^0 00′ W longitude. The total area of TNNP is 404 km^2, which supports the representative flora and fauna of the eastern most boreal forest of Atlantic Canada (Figure 1). The diverse habitats of the park contain 523 species of vascular plants (Brouillet et al. 1998), 200 species of moss (Hedderson 1987) and 100 species of lichen (Yetman et al. 1999). Amongst the vascular plants, 427 are indigenous to the area, 89 introduced, 29 rare and 7 hybrid species. Four main types (orders) of soil are classified in the TNNP such as Podzols, Regisols, Gleysols and Organics with Podzol being the dominant (Parks Canada 1984, 1977).

The entire 42 km section of the Trans Canada Highway (TCH) passing through the park (TNNP) was selected as the study site (Figure 1). The right-of-way of TCH extends 30 m on both sides of the road, covering a total area of 2.58 km^2 land of TNNP (Mallik 2000). Four distinct types of microhabitats, such as shoulder, side slope, ditch and back slope are observed along the TCH with different biophysical properties (Figure 2 a, b). The shoulder with approximately 2 m width is located next to the pavement. The shoulder has heavily compacted gravel for stabilizing the pavement necessary for vehicle movement. The side slope is located next to shoulders, which has variable widths, ranging from 2-6 m. The side slope is also constructed with course mineral soil for the purpose of slope stability. The ditch with 2-4 m width lies next to the side slopes. The ditch is located at the end of side slope for drainage of surface run off and seepage water. The back slope located at the end of the right-of-way and close to the original forests with natural soil and biota that has a width of 4-10 m (Figure 2).

Roadside vegetation survey

A roadside vegetation survey was conducted in the summer (July-August) of 2001. Vegetation data were collected following a stratified random sampling procedure across the four microhabitats along the TCH. Vegetation data were collected from 34 transacts laid out randomly along the road sections that were not disturbed for the last 10-15 years by reconstruction activities (Appendix 2). All transacts were laid out

perpendicular to the pavement and extending up to the edge of the forest. The length of transacts varied between 30 to 40 m depending on the width of the right-of-way. Newly re-constructed road sections, bridges, culverts and other man-made structures along the TCH were not included in the vegetation survey. Roadside habitats along the TCH were stratified into four microhabitats, such as shoulder, side slope, ditch and back slope for vegetation sampling (Figure 2). On each transect, 4 to 6 quadrats (1 m x 1 m) were placed across the microhabitats. The number of quadrats within each microhabitat varied depending on the width of the microhabitat (Appendix 2).

The percent cover of all plants was noted from 1 m x 1 m quadrats, placed systematically in all microhabitats along each transect. Most plants were identified up to species, except some that were difficult to distinguish in the field without flowers or fruits. All graminoids were recorded as grass. Several common and distinctive bryophytes and lichens were identified to species level. The plants were grouped into six life forms, such as tree, shrub, herb, grass, bryophyte and lichen. Only seedlings and saplings of tree were considered in the vegetation sampling. A study of species diversity was conducted under a broader category of six life forms containing species that have more than 10% cover. Consequently, the diversity study focused on a restricted number of commonly occurring native plants along roadside habitats. Nomenclature and identification of all the vascular and nonvascular plants followed Legasy et al. (1995), Ryan (1978) and Vitt et al. (1998). The nomenclature of plants was also verified with the US Plant Database Version 3.5 (2003).

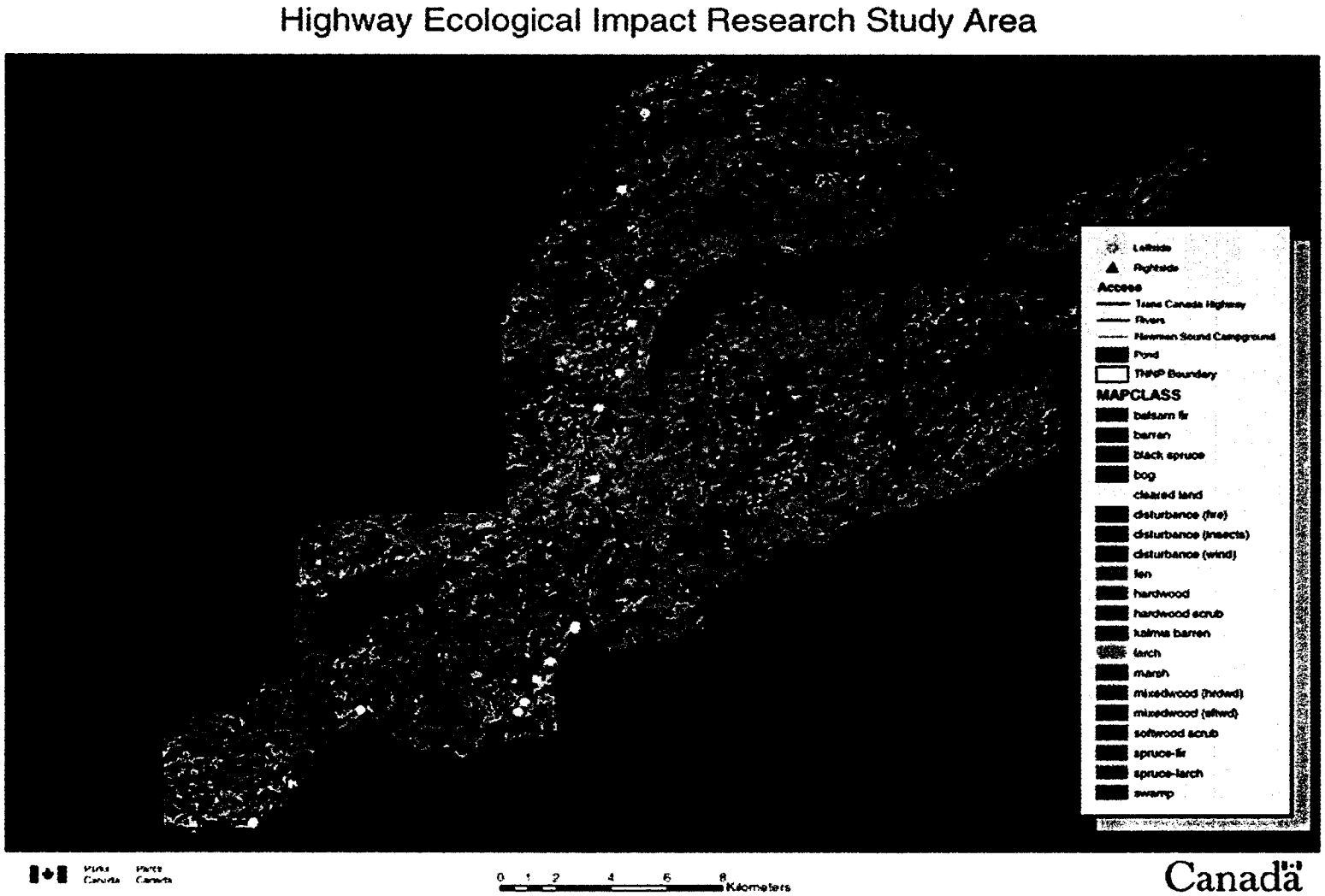


Figure 1. Vegetation map of Terra Nova National Park, Newfoundland. The red line indicates the 42 km section of the TCH, running in the north-south direction. Black triangles (▲) and yellow circles ( ) along TCH indicate the location of transects laid out at left and right side respectively.

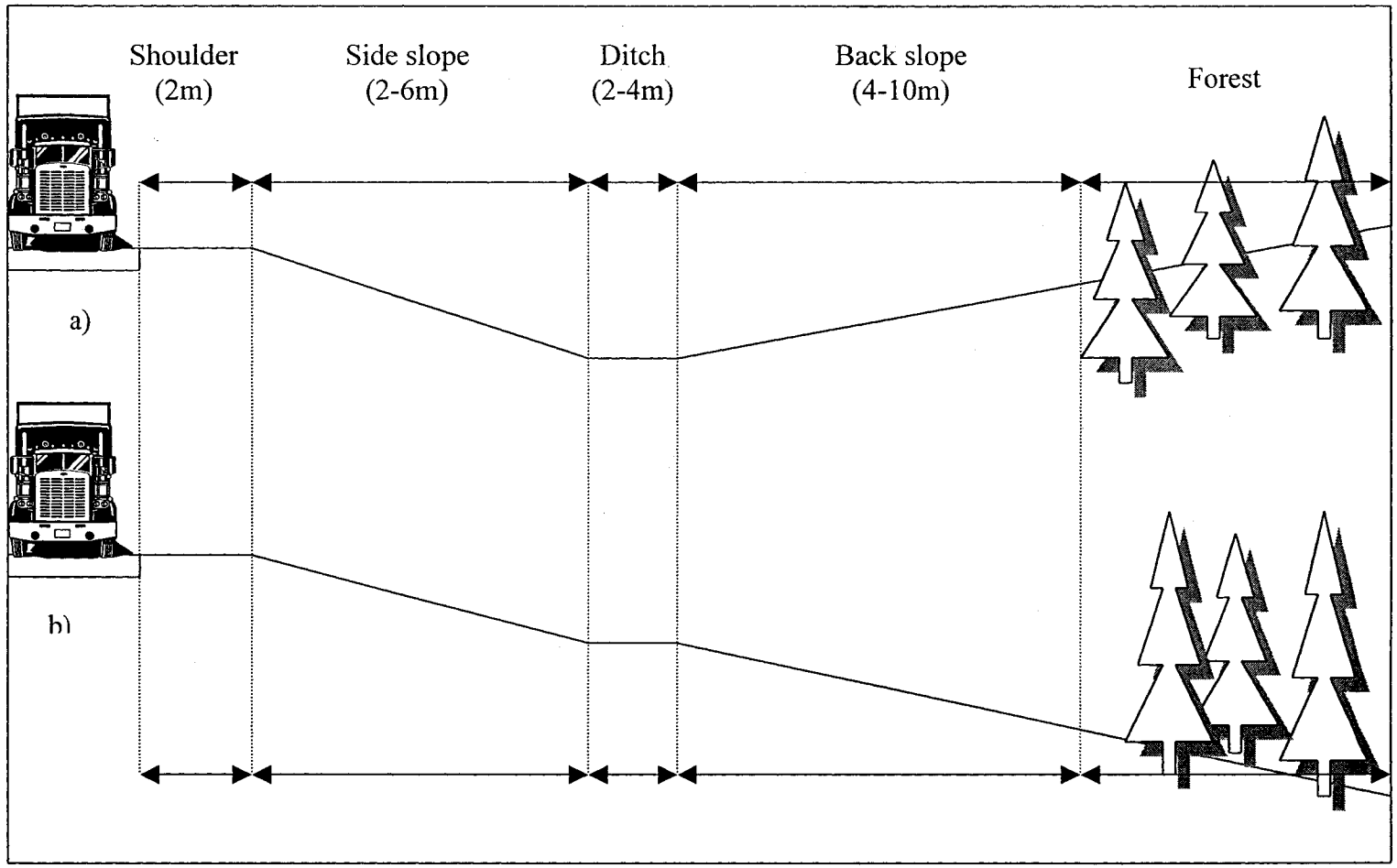


Figure 2. Typical cross section of the Trans Canada Highway (TCH) in Terra Nova National Park, showing four different roadside microhabitats including pavement and adjacent forest, a) with inclining back slope to the forest and b) with declining back slope to the forest.

Sampling of roadside substrates

In August 2002, soil samples were collected from four microhabitats along a transect perpendicular to the pavement. A total of 40 sample plots were located across four microhabitats at ten randomly laid transects along 10-15 year-old sections of the TCH. On rainless days, 500 g soil sample was collected from three different depths: 5, 15 and 40 cm of an excavated pit, located at every sample plot. Soil pH and moisture content were determined by an electrometric method, using a pH and moisture meter (Kelway Soil ® Acidity and Moisture Tester Model HB-2, Rittenhouse, St. Catharines, ON, Canada). The equipment was used to measure soil pH and percent moisture content, directly from soil samples. Soil dry bulk density (g/cm^3) was determined from wet bulk density, using the following equation:

Dry bulk density = [Wet bulk density (1-Moisture content x 0.01)].....(1)

Wet bulk density was taken by measuring weight of a known volume of fresh soil sample keeping in a plastic beaker.

Electric conductivity (μmhos/cm) was determined from the 1: 5 (soil: distilled water) slurry at a room temperature and was converted into 25^0 C, using the following formula:

EC ($25\ ^0$C) = [Conductivity measured /1 + 0.02 (Room temperature-$25\ ^0$C)].... ...(2)

Instrumental precisions were checked for the conductivity meter and cell by calibrating in a prepared standard solution (0.0005 M and 0.001 M) KCl. The depth of organic matter was measured by a steel ruler graduated in millimeters from the excavated soil pit in different microhabitats.

Assessment of maintenance disturbances

The entire right-of-way is exposed to various maintenance disturbances of different intensities and frequencies, such as snow plowing in the winter, brushwood cutting for traffic visibility and ditch clearing for efficient drainage. Disturbance patterns were categorized by the continuity and discontinuity of different roadside management

activities. The shoulder experienced continuous and severe maintenance disturbance due to snow plowing every winter. The side slope and ditch experienced occasional disturbance due to brushwood cutting and ditch cleaning at an interval of 5-10 years. The back slope, located at the end right-of-way, experienced low maintenance disturbances. All the three types of maintenance disturbances were estimated categorically from the quadrats that showed signs of brushwood cutting and ditch cleaning. In the quadrats, the presence of stumps and fresh soil excavation indicated brushwood cutting and ditch clearing respectively. Categorization of maintenance disturbances was done in the field during the vegetation survey from the quadrats used for plant cover estimation.

Above and below ground plant architectural characteristics and biomass allocation patterns

This study was conducted in August 2002. Ten species were selected out of 22 dominant species that were found significantly abundant and frequent in respective roadside microhabitats by Indicator Species Analysis. Details of Indicator Species Analysis method will be discussed later in the data analysis section. Above and below ground plant architectural characteristics and biomass allocation patterns of ten dominant roadside species were investigated by excavating their root systems followed by a destructive sampling. The dominant species from the shoulder were *Achillea millefolium* and *Plantago major*, from the side slope *Anaphalis margaritacea*, *Empetrum nigrum, Juniperus communis, Vaccinium angustifolium* and *Trifolium repens*, from the ditch *Spiraea latifolia* and from the back slope *Clintonia borealis* and *Cornus canadensis*. Other dominant plants that have either delicate or robust roots were excluded because of excavation difficulties. The selected plants had a cover value between 10-20 % of a 1 m x 1 m quadrat.

Above and below ground plant architectural characteristics were determined from ten individual plants of each dominant species. The maximum stem height was noted from the difference between ground surface and top of the shoot. Shoot spread was determined in two steps: first, a mean diameter of the above ground spread of individual plant was calculated from two diameter measurements, taken perpendicular to each other. The longest diameter was measured and then the second diameter was taken

perpendicular to the first one, passing thorough the stem base. Second, the area covered by the above ground part of the individual plant was determined by the following formula:

$$\text{Shoot spread} = \pi (D/2)^2. \quad \ldots\ldots (3)$$

Where,

$D = (D_1 + D_2)/2$

D = mean diameter of the above ground spread

D_1= the longest diameter of the above ground spread passing through the stem base

D_2= the longest diameter of the above ground spread perpendicular to D_1 passing through the base of the stem

Below ground plant architectural characteristics were determined by removing the topsoil to detect the root system of individual plant, followed by excavating the entire below ground parts. The maximum root depth was determined by excavating the major root from the base of the plant vertically extended to the soil. The maximum root depth was measured from the vertical distance between the soil surface and the tip of the main root. The maximum rooting depth of *Clintonia borealis* and *Cornus canadensis* was measured by excavating vertically oriented root from the runner.

To measure depth of lateral roots, the main branch roots that extend laterally from the base of the root were detected and exposed by removing the topsoil, keeping the root systems undistorted below the ground. The depth of lateral roots was determined by averaging the depth of lateral brunch roots at ten random points taken by a wooden ruler-scale without distorting the original alignment of the root system.

Below ground spread was determined by calculating the area covered by the entire root system. To determine the area, the mean root diameter of was calculated by averaging the diameter of the longest lateral root and the root perpendicular to the longest lateral root, passing through the base of the plant. Area of the root spread was also determined by using the same formula used for measuring shoot spread.

The plant samples were first dried in the air and than brought to the laboratory for oven drying. The sample plants were separated into leaf, stem, root and rhizome in order to determine the dry biomass of the plant components by oven drying at 65 ^{0} C until a constant weight was attained.

Data Analysis

Multi-Response Permutation Procedure (MRPP)

The multi-response permutation procedure (MRPP) (Zimmerman et al. 1985) was used to test the null hypothesis of no floristic difference among the four roadside microhabitats. Williams (1983) suggested the MRPP as a non-parametric method that implements multivariate tests of the null hypothesis of no difference between a *priori* groups of samples. The MRPP has become a unique statistical technique, analogous to the Discriminant Function Analysis (DFA), as the technique can avoid many of the assumptions of DFA to deal with various types of ecological data (Williams 1983). The MRPP mainly avoids the assumption of multivariate normality and equal variance that are seldom met with ecological community data. The MRPP is able to differentiate the multivariable treatment differences by considering the reality of ecological data. Although MRPP avoids assumptions of multivariate normality and equal variance, this method is strictly applied, when the following assumptions are met: a) the sample units are independent to avoid pseudoreplication, b) the relative weighting of the variables has been controlled prior to calculating the distance measure, and c) the distance measure chosen adequately represents the variations of the interest of the data (McCune and Grace 2002).

The MRPP compares the observed intra-group average distance with the average distance that would have resulted from all the other possible combinations of the data under the null hypothesis. The observed delta is determined by averaging the observed intra-group distances, weighted by the relative group size. The observed delta is compared to the probability delta, resulting from every permutation of all the observations among the groups. A probability value of a delta smaller than the observed is calculated from the position of the observed delta in the list of possible deltas. As the number of possible permutations to be calculated is frequently very large, a test statistic T

is calculated from Pearson Type III distribution to derive the probability (Mielke and Berry 1984). A third statistic A, or the chance corrected within group agreement, calculated from the observed and expected deltas, is used to measure the homogeneity within the group. An A=1 indicates that all samples within each group are identical, while an A=0 indicates that within group heterogeneity is equal to that expected by chance. An A<0 indicates that the heterogeneity within the group is greater than that expected by chance.

Indicator Species Analysis

The Indicator Species Analysis, a non-parametric method, was used to detect and describe the value of different species indicating environmental conditions (Dufrene and Legendre 1997). The ISA is a simple procedure for identifying those species that show significantly preferential distribution (frequency and abundant) with respect to *a priori* treatment group. An indicator value is calculated by multiplying the relative abundance of each species in a particular group and the relative frequency of the species occurrence in the sample of that group. The significance of the indicator values is evaluated using the Monte Carlo procedure of randomization, where samples are reassigned and recalculated. The number of randomized indicator values higher than the observed values are used to calculate the probability value (McCune and Grace 2002).

Canonical Correspondence Analysis (CCA)

The Canonical Correspondence Analysis (CCA) was used to relate the quantitative changes in species abundance with environmental variables (ter Braak 1986; Palmer 1993). The CCA is appropriate when the objective is to describe community structure with respect to particular sets of environmental variables (McCune 1997). The CCA is best suited to community data sets where species responses to environmental are unimodal (hump-shaped). A Monte Carlo test using 1000 randomizations was applied to evaluate the statistical significance of the correlation between the species and environmental matrix (McCune and Grace 2002). The resulting ordination diagram expresses not only a pattern of variation in species composition but also the main relations between the species and each of the environmental variables. The joint plot of

species points and environmental arrows is actually a bi-plot that approximates the weighted averages of each of the species with respect to each of the environmental variables. The position of the head of the arrows depends on the eigenvalues and intra-set correlations. Environmental variables represented by long arrows have stronger correlation with the ordination axis than those with the short arrows (Jongman et al. 1995).

Non-parametric test of significance and multiple comparisons

The Kruskal-Wallis non-parametric *H* test of significance (Kruskal and Wallis 1952) was used to test the null hypothesis of no difference of substrate properties and plant architectural characteristics and biomass allocation patterns among the roadside microhabitats. The non-parametric *H* test is applied when the data do not meet the assumptions of normal distribution and equal variance for parametric significance test. Before performing the non-parametric null hypothesis testing, the data were justified by Kolmogorov-Smirnov (K-S) test of normality and Levene's test of equal variance. Kruskal and Wallis (1952) developed a distribution free test that is analogous to the one-factor ANOVA F test. The Dunnet T3, a multiple comparison method, developed by Dunnet (1980) was also applied to compare the treatment differences of the data with unequal variance. All the multivariate tests and analyses, such as MRPP, ISA, and CCA were carried out using the PC-ORD Version 4 Program (McCune and Mefford 1999) and the nonparametric test statistics using SPSS version 9.0 (SPSS 1999).

Results

Floristic patterns

The roadside vegetation along the TCH in TNNP is highly diverse. In this study, a total of 65 vascular and non-vascular plants were recorded from four roadside microhabitats (Appendix 1). The MRPP showed that floristic composition in terms of species abundance were significantly different among the four microhabitats along the TCH ($T = -2.081$, $P \leq 0.05$). A summary of the MRPP statistics is presented in Table 1. The low value of the third statistics A of the MRPP indicated heterogeneity of plant abundance within the samples of a particular microhabitat. The marginal difference between expected delta and observed delta of the MRPP also indicates subtle differences of plant abundance among the roadside microhabitats.

Patterns of plant life forms

In general, the lowest species richness and plant cover of six plant life forms were found in the shoulder when compared to the other roadside microhabitats (Table 2). However, the shoulder was richer in herbaceous species with higher plant cover than that of the other plant life forms (Table 2). The side slope represented wider varieties of plant life forms than the shoulder. In the side slope, species richness of herbs was slightly lower than that of the back slope; however the highest herbaceous plant cover was found in the side slope (Table 2). Species richness of shrubs was lower in the side slope than the back slope, but the cover value was similar to the back slope. Species richness and plant cover of all the life forms in the ditch were more or less similar to the side slope and back slope, but the ditch had higher grass cover than the other microhabitats. Species richness and plant cover value of all the plant life forms were higher in the back slope than the other microhabitats (Table 2). Richness of bryophytes and cover was higher in the side slope, ditch and back slope compared to the shoulder.

The Indicator Species Analysis (ISA) also showed that 22 species of different plant life forms were significantly higher in abundance and frequency in their respective microhabitats than the other plants (Table 3). *Achellia millefolium* and *Plantago major*, the representatives of herb life form, were significantly frequent and abundant in the shoulder. In side slopes, *Anaphalis margaritacea*, *Epilobium angustifolium* were the most

abundant and frequent herbaceous life form. *Juniperus communis* and *Empetrum nigrum*, the representatives of shrub life from, were also significantly frequent and abundant in the side slope. *Spiraea latifolia* and *Alnus rugosa*, the woody erect shrubs, were significantly abundant and frequent in the ditch. *Clintonia borealis* and *Cornus canadensis,* the two abundant herbs, were frequently found in the back slope. The abundance and frequency of two shrubs, such as *Kalmia angustifolia* and *Ledum groenlandicum* were significantly higher in the back slope than the other microhabitats. *Hylocomium splendens*, the only bryophytes found significantly abundant in the back slope. None of these indicator values of the other species were particularly high, however, reflecting the fact that all of these species were found, at least occasionally, in the four microhabitats.

Table 1. Results of the MRPP tested the null hypothesis of no floristic differences among the roadside microhabitats. The average distance is the mean Euclidean distance between each pairwise combination of quadrats from a particular microhabitat. N is the number of quadrats sampled in each microhabitat. The observed delta is calculated from the data while the expected delta is derived from a null distribution. T is the MRPP test statistic, and A is the chance corrected within-group agreement. The MRPP was significant ($P \leq 0.0353$).

Microhabitat	Average distance	N	MRPP statistics
Shoulder	90.269	37	Observed delta=94.26
Side slope	96.806	41	Expected delta=94.74
Ditch	93.692	26	T=-2.081
Back slope	94.907	60	A=0.00505

Table 2. Mean vegetation cover (%) and species richness of the six plant life forms of four microhabitats along TCH in TNNP, Newfoundland. Value within bracket indicates the mean species number of respective life forms. The mean cover (%) value and species number of the six life forms were determined from 37, 41, 26 and 60 quadrates located in the shoulder, side slope, ditch and back slope respectively. Species of any life form, less than 10 % vegetation cover was excluded in determining the mean value.

	Microhabitats			
Life forms	Shoulder	Side slope	Ditch	Back slope
Tree	0 (0)	9.55 (4)	9.56 (2)	11.96 (4)
Shrub	10.21 (2)	24.24 (8)	22.92 (10)	24.14 (14)
Herb	20.32 (7)	33.07 (23)	33.54 (22)	30.68 (28)
Grass	4.21 (NC)	7.92 (NC)	15.67 (NC)	8.64 (NC)
Bryophyte	0.43 (3)	27.85 (8)	38.08 (11)	42.67 (13)
Lichen	0.35 (2)	2.88 (4)	1.78 (3)	7.43 (5)

NC = Number of species under grass life form was not counted

Note: Some species belong to the same life form were found more than one in microhabitats.

Table 3. Indicator values of common plants found in four roadside microhabitats. The data matrix contains 60 plots and 65 species. Observed indicator values summarize the relative frequency and abundance of each species at the microhabitat, where they are most abundant. The mean randomized indicator values are calculated from 1000 Monte Carlo runs with randomized data. The *P*-value is the proportion of randomized runs that had indicator values higher than the observed value. *P*-value was considered significant at a 0.05 % level.

Species	Microhabitat	Observed Indicator Value	Mean Randomized Indicator Value	*P*-value
Achillea millefolium	Shoulder	41.8	21.40	0.015
Plantago major	Shoulder	55.0	15.56	0.002
Anaphalis margaritacea	Side slope	57.9	24.40	0.004
Empetrum nigrum	Side slope	30.0	10.90	0.050
Juniperus communis	Side slope	33.5	12.30	0.027
Vaccinium angustifolium	Side slope	16.6	14.10	0.031
Trifolium repense	Side slope	21.0	13.90	0.045
Fragaria vesca	Side slope	30.8	12.70	0.026
Epilobium angustifolium	Side slope	50.0	12.40	0.003
Spiraea latifolia	Ditch	32.7	12.60	0.032
Aster spp.	Ditch	40.0	12.60	0.011
Grass	Ditch	34.5	29.10	0.041
Alnus rugosa	Ditch	45.9	18.10	0.005
Rubus pubescens	Ditch	43.6	19.60	0.016
Kalmia angustifolia	Back slope	76.7	18.40	0.001
Clintonia borealis	Back slope	41.5	14.40	0.004
Cornus canadensis	Back slope	34.7	17.30	0.048
Ledum groenlandicum	Back slope	47.4	17.30	0.007
Linnaea borealis	Back slope	44.9	18.70	0.009
Trientalis borealis	Back slope	40.0	11.80	0.011
Rhytidiadelphus triquitrus	Back slope	39.5	24.01	0.035
Hylocomium splendens	Back slope	50.0	12.80	0.001

Substrate properties of roadside microhabitats

Substrate properties of roadside microhabitats were significantly different from each other. In general, the ditch and back slope were comparatively wetter than the shoulder and side slope. Among the roadside microhabitat, soil moisture content was highest in the ditch (45 %), but did not differ significantly from the value of back slopes (38 %). Substrate in the side slope was moist, but it was extremely dry in the shoulder. The shoulder had significantly lower moisture content (10 %) compared the other microhabitats. Substrate side slopes was significantly higher in moisture content (15 %) than that of the shoulder (Table 4).

The highest soil bulk density (1.06 g/cm^3) and no detectable organic matter depth were recorded in the shoulder (Table 4). Substrate of the side slope and ditch had a similar trend of soil bulk density and organic matter depth, as the value did not differ significantly (Table 4). A significantly higher depth of organic matter was found in the back slope than the other microhabitats (Table 4). Substrate of back slopes had significantly lower bulk density (0.36 g/cm^3) compared to the other microhabitats (Table 4).

The electric conductivity of substrate among the microhabitats did not vary significantly. However, the pH was significantly different among the microhabitats. Substrate in shoulders had the highest pH value (6.89), but did not vary significantly with the value of the side slopes (6.80). Whereas substrate in the ditches and the back slopes was significantly similar in pH value, but was significantly lower than the shoulders and side slopes (Table 4).

Table 4. Substrates properties of four roadside microhabitats along the TCH in TNNP, Newfoundland. Substrate properties of were determined from soil samples (N=30/microhabitat) collected at three different depths, 5, 15 and 40 cm of a soil pit. Values are median (minimum and maximum values within parentheses), as the Kruskal-Wallis nonparametric *H* test is done by analysis of variance of ranks derived from the sample with the same median.

	Substrate Properties				
Microhabitat	Moisture content (%)	Bulk density (g/cc)	OM depth (mm)	pH	Conductivity. (µmhos/cm)
Shoulder	10 (5-12) c	1.06 (0.89-1.33) a	0	6.89 (6.80-6.90) a	86.79 (79.59-100) a
Side slope	15 (8-50) b	0.78 (0.42-1.24) b	20 (5-50) b	6.80 (6.25-6.90) a	93.61 (63.83-136.17) a
Ditch	45 (15-55) a	0.70 (0.39-1.32) b	40 (10-70) b	6.45 (5.30-6.81) b	82.97 (57.69-136.90) a
Back slope	38 (10-65) a	0.36 (0.14-1.02) c	120 (50-200) a	6.52 (5.80-6.88) b	92.92 (74.47-189.87) a

Kruskal-Wallis non-parametric *H* tests of the original values of all the substrate properties indicated significant ($P \leq 0.05$) microhabitat-to-microhabitat differences. Unlike letters in a column indicate values significantly different at 0.05 level determined by Dunnett's T3 (*Post Hoc*).

Vegetation patterns of roadside microhabitats in relation to substrate properties

The Canonical Correspondence Analysis (CCA) performed well to ordinate species abundance in four roadside microhabitats with respect to the environmental variables (Figure 3). There was a strong correlation between the plot scores based on species composition and that based on the environmental variables (r = 0.927; Monte Carlo test $P \leq 0.003$). The first CCA axis based on the five environmental variables explained only 7.6 % of the variation in the species data with an Eigen value of 0.558 (Table 5). The low Eigen value indicated poor explanation of the CCA axes in terms of species abundance and hence by the environmental variables. The biplot of the CCA ordination is shown in Figure 3. The eigenvalues of the first two axes (λ_1= 0.55 and λ_2=0.33 respectively) indicate plant community separation along measured gradients (Table 5). The four distinct microhabitats with different substrate properties and species abundance were also separated well by axis 1 in the CCA bi-plot (Figure 3). The dominant environmental variables correlated with the axis 1 were organic matter depth, substrate dry bulk density and moisture content (Table 5). The strongest correlation of the organic matter depth, substrate dry bulk density, and moisture content with axis 1 was represented by the longest arrows in the CCA biplot (Figure 3). Separation of vegetation plots located on shoulder and back slope is represented by the point clustered left quadrants and middle portion of the right quadrant of the CCA biplot respectively (OM depth and bulk density). Separation of vegetation plots located on the ditch is represented by the point clustered on the upper right quadrant (moisture content). CCA ordination of 65 roadside plants (result not presented) indicated that *Achellia millefolium* and *Plantago major* dominated shoulder plant community with high bulk density and poor organic matter depth (Figure 3). The side slope plant community, dominated by *Anaphalis margaritacea*, *Epilobium angustifolium, Juniperus communis* and *Empetrum nigrum*, and *Trifolium repens*, were separated and located at lower-middle portion of the left quadrant. *Spiraea latifolia* and *Alnus rugosa* were dominated in the ditch, where the moisture content was high. *Clintonia borealis* and *Cornus canadensis, Kalmia angustifolia, Ledum groenlandicum and Hylocomium splendens* were dominated in the organic matter rich back slope (Figure 3).

Table 5. Eigenvalue, variability, species-environment correlation, and correlation for the environmental variables with the ordination axes. All correlations listed below are 'intraset correlations' as described by ter Braak (1986). None of the correlated values between 65 roadside species and CCA axes was higher than 0.5.

Variable	Axis 1	Axis 2	Axis 3
Eigenvalue	0.554	0.300	0.227
Variables *	7.5	4.1	3.1
Spp-Envt †	0.927	0.895	0.774
OM depth	0.866	-0.300	0.145
Moisture	0.629	0.372	-0.129
Conductivity	0.307	0.409	-0.175
Bulk density	-0.699	0.380	0.578
Soil pH	-0.428	-0.067	0.085
P-value +	0.003	0.25	0.45

* Explain the % variability by the each CCA axes.

† Spp-Envt correlation refer to Pearson correlations between sample scores that are linear combinations of environmental variables and sample scores that are based on species data.

+ Monte Carlo test results for eigenvalues and species- environment correlations based on 1000 runs with randomized data.

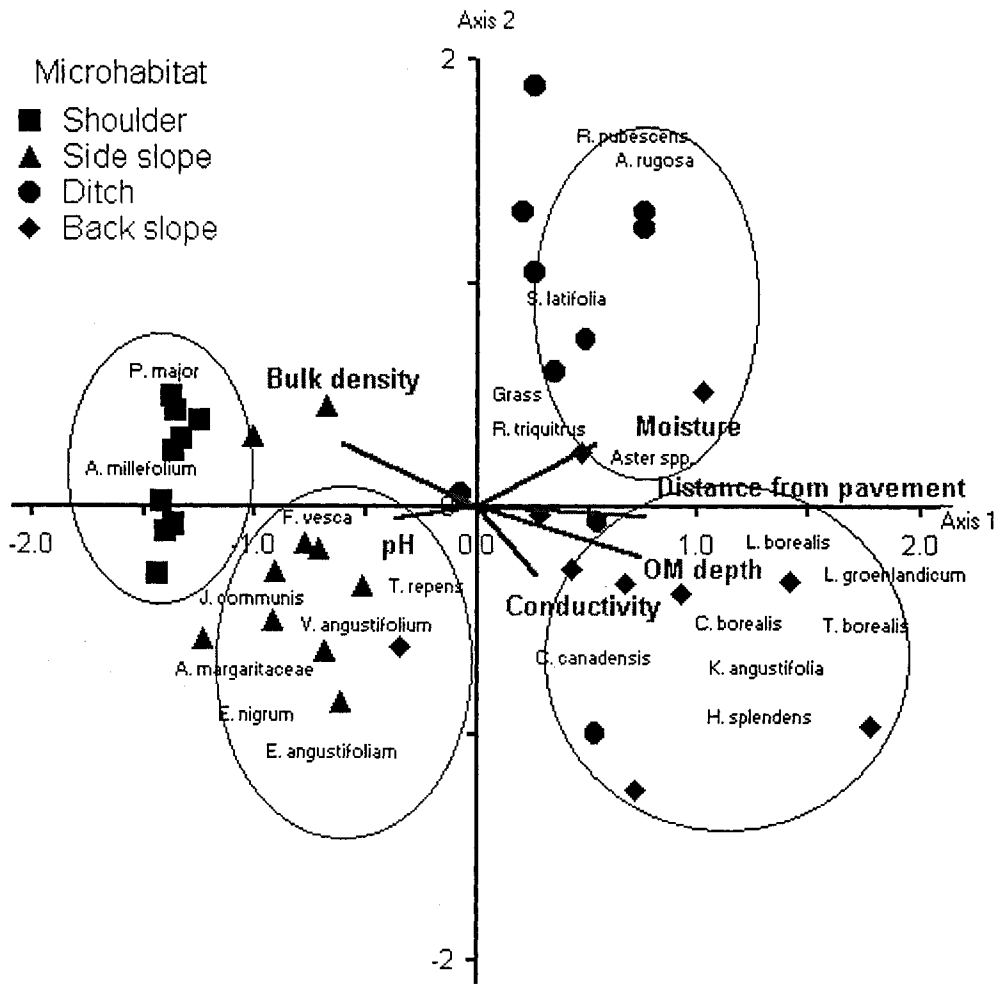


Figure 3. The CCA ordination of 40 plots and 65 plants (only the most frequent and abundant species identified by the Indicator Species Analysis as in Table 3 were shown in the ordination space) composition with five environmental variables, such as moisture content (%), organic matter depth (mm), bulk density (g/cc), pH, electric conductivity (μmhos/cm) in four microhabitats (shoulder, side slope, ditch and back slope) along the roadsides of TCH, Terra Nova National Park. The Eigen value of Axis 1, $\lambda = 0.55$; and Axis 2, $\lambda = 0.30$, where Axis 1 describe the 7.6 % of the variability of the species data)

Roadside maintenance disturbances

The roadside microhabitats experience different patterns of maintenance disturbance due to the snow plowing, brushwood cutting and ditch clearing. The shoulder was exposed to most severe and frequent maintenance disturbance due to the snow plowing. More than 90 % of the sampled quadrats of the shoulder were exposed to snow plowing during every winter (Figure 5 a, b). The maintenance disturbance was less intense and less frequent in the side slope and ditch. Approximately 10 % of the quadrats in the side slope were exposed to seasonal snow plowing. The side slope and ditch was exposed to occasional brushwood cutting and ditch clearing at a periodic 5-10 year intervals (Figure 5 b). Approximately 80 % and 45 % of the quadrats were exposed to brushwood cutting in the side slope and ditch respectively. In the ditch, 30 % of the quadrats were exposed to ditch clearing (Figure 5 a). The back slope was rarely disturbed as more than 70 % of the quadrats were not exposed to any maintenance activities (Figure 5 a, b).

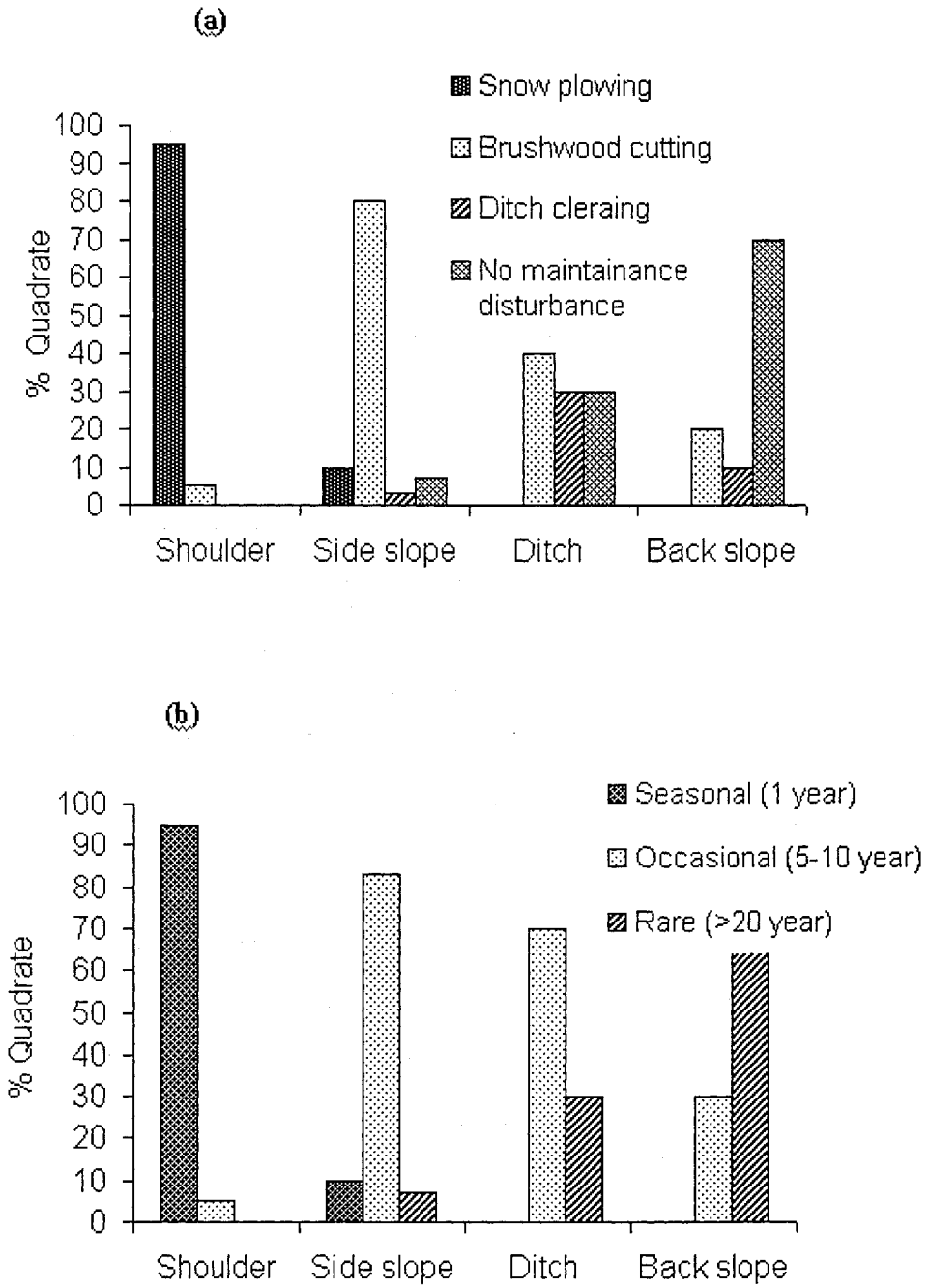


Figure 4. Maintenance disturbance patterns in the four roadside microhabitats along TCH in TNNP, Newfoundland: (a) percentage of quadrats exposed to the three types of maintenance disturbance (b) percentage of quadrats exposed to different frequency of maintenance disturbance.

Above and below ground plant architectural characteristics and biomass allocation patterns

Despite the difference in species-specific phenotypic traits, dominant plants of a particular microhabitat of the TCH tend to have similar above and below ground plant architectural characteristics and biomass allocation patterns. In general, the dominant plants in the shoulder, side slope and ditch allocated high amounts of biomass to the above ground parts of the plant; whereas, the abundant plants of the back slope allocated higher amount of biomass to the below ground parts than the above ground plant parts.

In this result section, all values of above and below ground plant architectural characteristics and biomass allocation pattern are presented by the median (central value) of ten plant samples per species. Dominant plants of the side slope and ditch had more extensive and robust root-shoot structure than the plants of the other microhabitats (Table 6). Shoot height of *E. nigrum* was low (10 cm), but the above ground plant structure was quite extensive, covering an area of approximately 1352 cm^2 per plant (Table 6). *E. nigrum* allocated approximately 85 % of its total dry biomass to the above ground part of the plant. *J. communis*, a woody shrub, had very robust and extensive above ground structure with 18 cm shoot height and covered an area of approximately 707 cm^2 per plant (Table 6). *J. communis* also allocated 80 % of its dry biomass to the above ground parts of the plant (Table 7). The below ground plant parts of *J. communis* and *E. nigrum* were not as robust as their above ground parts, but penetrated deep into soil and had spreader root systems, compared to the plants of other microhabitats. The tap-root of *E. nigrum* and *J. communis* penetrated approximately 20 and 10 cm vertically into soil respectively. The lateral roots of these species were brunched out from the tap-root, spreading an area between 5260 and 12260 cm^2 per plant and maintaining a depth of 6-7 cm from the ground surface (Table 6).

The other dominant plants of the side slop, such as *Anaphalis margaritacea*, *Vaccinium angustifolium* and *Trifolium repens* also had an extensive above ground structure. The above ground part of these species was spreader than that of the dominant plants of the other microhabitats. Shoot spread of these species was approximately between 397 and 935 cm^2 per plant (Table 6). These species were deep rooted with widespread fibrous root system. The maximum root depth of *A. margaritacea*, *V.*

angustifolium and *T. repens* was 17, 12 and 25 cm respectively (Table 6). These species also had deeper lateral branch roots, as had the other species in the side slope. Lateral root depth of these species varied between 5 and 8 cm (Table 6). Regarding biomass allocation patterns, these species also had similarities with other dominant plants of the side slope as two-thirds of total biomass was allocated to above ground parts of the plant (Table 7). Approximately 60-70 % of the total dry biomass of these species of the side slope was allocated to the above ground parts (Table 7).

The above and below ground architectural characteristics and biomass allocation pattern of *Spiraea latifolia*, the representative dominant plant of the ditch, were similar to the dominant plants of side slope. Although *S. latifolia* had an erect and woody above ground part with 21 cm shoot height, the shoot was less spreaded, as the plant covered an area of 103 cm^2 per plant (Table 6). Below ground structure of *S. latifolia* was shallower and less spread than the dominant plants of the side slope. Maximum depth of tap-root and lateral roots was 10 cm and 5 cm respectively and whole root system occupied an area of 108 cm^2 per plant (Table 6). *S. latifolia* also allocated approximately 70% of the total biomass to the above ground parts (Table 7).

In the shoulder and back slope, the dominant plants had smaller above ground structure with shallower root systems than that of the dominant plants of the side slope and ditch. Although *Achillea millefolium*, the dominant plant in shoulder, had 21 cm tall shoot, the above ground parts covered an area of 276 cm^2 per plant. *Plantago major,* the other dominant plant of the shoulder had 10 cm shoot height and the above ground parts covered an area of 104 cm^2 per plant. A few vertically oriented roots of both the species penetrated 7-11 cm deep in to the soil, however, the whole fibrous root system was quite shallow and less spread. Below ground parts of the two species occupied an area between 53 and 262 cm^2 per plant with a shallow lateral root depth of 3 to 5 cm (Table 6). Plants in the shoulder allocated 50-60 % of the total biomass to the above ground parts of the plant (Table 7).

In the back slope, above and below ground structure and biomass allocation patterns of *Clintonia borealis* and *Cornus canadensis* were totally different from the plants of other microhabitats. Height of ramet (shoot height) of these species ranged between 5 and 8 cm. Ramet of these species covered an area of 40-50 cm^2 per plant.

Some delicate lateral roots branched out from the node of the ramet and the runner extended 6-7 cm vertically deep in to soil keeping a lateral depth of 3 cm (Table 6). These two dominant herbs of the back slope allocated approximately 60 % of the total biomass to the below ground parts (Table 7).

Table 6. Above and below ground plant architectural characteristics of the ten dominant species of the four roadside microhabitats along the TCH in TNNP, Newfoundland. Ten individuals of each species (N=10/species) were studied to determine the above and below ground architectural characteristics. Values are median (minimum and maximum values within parentheses) of the ten sample plants per species, as the Kruskal-Wallis nonparametric *H* test is done by analysis of variance of ranks derived from the populations with the same median.

	Above and below ground architectural characteristics				
Species/ microhabitat	Max. shoot height (cm)	Max. root depth (cm)	Lateral root depth (cm)	Root spread (cm^2)	Shoot spread (cm^2)
Shoulder					
Achillea millefolium	21 (19-25)	10 (8-14)	5 (4-6)	262 (133-363)	276 (189-452)
Plantago major	10 (8-12)	7 (6-10)	3 (2.5-3)	53 (38-95)	104 (50-201)
Side slope					
Anaphalis margaritacea	31 (24-35)	17 (14-23)	6 (5-8)	2375 (1772-5216)	397 (240-706)
Empetrum nigrum	10 (7-15)	20 (15-25)	7 (5-9)	5260 (1963-8659)	1352 (829-20830)
Juniperus communis	18 (13-25)	10 (15-26)	6 (5-7)	12260 (2375-24052)	707 (415-881)
Vaccinium angustifolium	12 (9-15)	12 (10-15)	5 (3.5-6)	4437 (2827-8659)	462 (213-593)
Trifolium repens.	25 (5-29)	25 (10-45)	8 (6-11)	1486 (1075-1924)	935 (63-1924)
Ditch					
Spiraea latifolia	21(19-25)	10 (8-13)	5 (4-6)	1924 (907-2733)	403 (256-613)
Back slope					
Clintonia borealis	5 (4-7)	6 (4-8)	3 (2.5-4)	47 (19-95)	21 (9-33)
Cornus Canadensis	9 (6-10)	6 (4-8)	2.75 (2-3)	28 (19-78)	16 (5-33)

Kruskal-Wallis non-parametric *H* tests of the original values of above and below ground architectural characteristics indicated significant ($P \leq 0.05$) microhabitat -to- microhabitat differences.

Table 7. Above and below ground dry biomass allocation of the ten dominant species from four roadside microhabitats along the TCH in TNNP, Newfoundland. Ten individuals of each species (N=10/species) were studied for determining above and below ground biomass allocation patterns. Values are median (minimum and maximum values within parentheses) of the ten sample plants per species, as the Kruskal-Wallis nonparametric *H* test is done by analysis of variance of ranks derived from the populations with the same median.

	Dry biomass allocation			
Species/microhabitat	Root dry biomass (g)	Shoot dry biomass (g)	Total plant biomass (g)	Root-shoot ratio
Shoulder				
Achillea millefolium	2 (1- 4)	5 (2-9)	7 (3-12)	0.43 (0.33-1.20)
Plantago major	2 (1-3)	3 (2-5)	5 (3-9)	0.64 (0.5-1)
Side slope				
Anaphalis margaritacea	7 (3-8)	11 (6-13)	18 (9-21)	0.65 (0.51-0.75)
Empetrum nigrum	2 (2-4)	19 (15-35)	22 (17-39)	0.12 (0.1-0.14)
Juniperus communis	5 (2-6)	20 (14-25)	25 (17-31)	0.22 (0.16-0.25)
Vaccinium angustifolium	4 (2-4)	8 (4-9)	11 (6-14)	0.45 (0.36-0.51)
Trifolium repens	3 (2-5)	9 (5-21)	12 (7-25)	0.26 (0.23-0.45)
Ditch				
Spiraea latifolia	3 (2-4)	6 (4-9)	9 (5-13)	0.48 (0.42-0.51)
Back slope				
Clintonia borealis	2 (1-4)	1 (1-3)	3 (2-7)	1.43 (1-2.27)
Cornus Canadensis	2 (1-3)	1 (1-2)	3 (2-5)	2 (1.35-2.29)

Kruskal-Wallis non-parametric *H* tests of the original values of above and below ground dry biomass allocation indicated significant ($P \leq 0.05$) microhabitat -to- microhabitat differences.

Discussion

Vegetation patterns along the roadside microhabitats

There is a significant difference in roadside plant community composition among the four microhabitats tested by the MRPP. However, the marginal difference between expected delta and observed delta of the MRPP suggested subtle difference in species abundance among the roadside microhabitats. This subtle difference in roadside plant communities is reflected by low value of third statistics *A* of the MRP, as the plant abundance was heterogeneous within a microhabitat. Abundance of various species within the respective microhabitat was highly variable, which reduced the difference between the observed and expected mean values. The interpretation of MRPP statistics suggested that despite the heterogeneity of plant abundance within microhabitats, the floristic composition of roadside microhabitats was significantly different.

The results of CCA supported the argument of floristic difference across the roadside microhabitats in relation to substrate properties. Substrate properties were significantly different among the roadside microhabitats. Abundance of plants was significantly correlated with substrate properties. The Eigen value was low and the first CCA axis did not show a strong separation perhaps due to high variability or low sample size, nonetheless, the CCA suggested that four roadside microhabitats had distinct plant communities. Cilliers and Bredenkamp (2000) suggested similar floristic patterns, when their ordination diagrams showed the distribution of plants communities along the environmental gradient related to roadside substrate properties. Regarding the role of maintenance disturbance, although strong quantitative evidence was not presented in this study, Parr and Way (1988) experimentally demonstrates the effect of brushwood cutting on roadside plant compositions.

Vegetation patterns in shoulders

The shoulder has the most inhospitable environment for plant colonization and establishment. The shoulder supports a plant community with the poorest species richness and abundance of plant life forms. Only a few dominant herbs represent the plant community of the shoulder along the roadside. *A. millefolium* and *P. major* were found more abundant and frequent in the shoulder suggested by the Indicator species analysis.

Stress resulting from insufficient soil resources and severe maintenance disturbance may not allow colonization of diverse plant life forms in the shoulder (Grime 1977). Nonetheless, special plant strategies such as dimorphic reproduction, special mode of dispersal may enable some facultative life forms to colonize in the shoulder (Grime 1979; McIntyre et al. 1995). *A. millefolium* and *P. major* are indicators of dry, nutrient poor and coarse soil (Hawthron 1974; Warwick and Black 1981). Seedlings of these species colonize in the bare ground from seeds, but eventually regenerate by both sexual and vegetative reproductive methods (Warwick and Black 1981; Hawthron 1974). They also produce numerous seeds with wind dispersing mechanism, to ensure successful colonization in severely stressed and disturbed habitats (Warwick and Black 1981).

Because of poor moisture and nutrient content in the shoulder, the dominant plants of this microhabitat are expected to allocate more energy to below ground parts for acquisition of moisture and nutrients (Tilman 1988). However, despite the fibrous roots and rhizome, dominant plants in the shoulder allocate more biomass to above ground parts than the below ground parts. The possible reason for this trend could be the compaction of substrate in the shoulder that may restrict the biomass allocation to the below ground parts (Small and McCarthy 2002). On the other hand, dominant plants of the shoulder (*A. millefolium* and *P. major*) tends to allocate higher amount of biomass to produce large leaves and numerous tiny wind dispersed seeds for their successful regeneration (Warwick and Black 1981).

Vegetation patterns in side slopes

The side slope supports a distinct plant community with more diverse and richer plant life forms than the shoulder. Herb abundance is comparatively higher in the side slope than the other microhabitats. But shrub richness is noticeably low in side slope when compared to the ditch and back slope. In the side slope, shrubs do not get enough time to establish due to brushwood cutting at 5-10 year intervals. It is evident from old-field succession that seedling of shrubs frequently become established during the first 10 to 12 years (William et al. 1974). On the other hand, physical removal of competitive shrubs by brushwood cutting may enhance diverse herbaceous plants to colonize in the side slope (William et al. 1974).

Diverse floristic composition in the side slope may result from niche differentiations, which allow coexistence of closely related species in a non-uniform environment (Beatty 1984). Early colonizer may affect the micro-site conditions by changing the substrate properties leading to niche differentiation. Less intense physical disturbance allows early colonizers to persist long enough for improving the soil conditions for the subsequent colonizers. This phenomenon improves micro-site conditions, which allow occupation of the same species, or the others and thus influence species richness (Connell and Slatyer 1977). In the side slope, the early colonizers such as *A. margaritacea* and *E. angustifolium* establish rapidly in the exposed soil by wind dispersed seeds and aggressive clonal growth (Halpern 1989). These early colonizers may improve the substrate properties and facilitate the establishment of shrubs *E. nigrum, J. communis* and *V. angustifolium* on the side slope (Bell and Tallis 1958).

Dominant plants of the side slope allocate 60-80 % of their biomass to the above ground parts and produce wide speared and robust above ground structure. Although they have wide spread root systems, they allocate low energy to the below ground parts. This pattern of biomass allocation may suggest that the substrates of the side slope have optimum nutrients and moisture that allow the plant to allocate more biomass to above ground parts to maximize the acquisition of photosynthate and secure their reproduction (Orians and Solbrig 1977; Bloom et al. 1985). *A. margaritacea* allocates more biomass to the above ground parts to produce numerous wind dispersed seeds for securing their successful colonization and establishment (Halpern 1989). *E. nigrum, J. communis,* and *V. angustifolium also* have large above ground structures that capture photosynthate and produce seeds (Bell and Tallis 1958). Optimum moisture and nutrient content in side slope and removal of tall shrubs and trees by brushwood cutting may affect the above and below ground architectural characteristics of dominant plants in the side slope. Removal of shade providing shrubs and trees encourage the dominant plants of the side slope to maximize their above ground spread for capturing light resources (Tilman 1988).

Vegetation patterns in ditches

Ditch is wet and exposed to occasional maintenance disturbance. There is a distinct floristic composition in this microhabitat, probably because of the multiple strategies of the dominant plants in response to wet conditions and low disturbance. Abundance of *A. rugosa*, the robust shrub indicates wet conditions of ditches and low maintenance disturbance. Wind dispersed seeds and efficient vegetative regeneration by sprouting also facilitate colonization and establishment of these plants along the ditch. Abundance of *Aster* spp. and *R. pubescens* also indicate the wet condition of the ditch. This two species also regenerate from buried seed banks and by vegetative methods (Kellman 1970; Marks 1974). *S. latifolia*, representative of ditch plant community was taken to study the biomass allocation patterns. Other species was not considered to study biomass allocation pattern for the excavation difficulties. However, the above and below ground architectural characteristics and biomass allocation patterns of *S. latifolia* was more or less similar to some of the dominant species of the side slopes, except its shallow and small below ground structure. The soil moisture content is known to be one of the important factors for the root architecture and biomass allocation pattern. Since the substrate of the ditch is wet, *S. latifolia* is adapted to the strategy of allocating less energy to the below ground parts in search of water. Moreover, regeneration of *S. latifolia* by seeds and above ground sprouting enables this species to allocate more energy to the above ground part.

Vegetation patterns in back slopes

Substrate properties of back slopes were significantly different from the other microhabitats. During road construction, whole shrubs and trees communities were removed from back slopes without disturbing the soil. Plant communities of back slopes were more or less similar to the plant communities of the adjacent forest. In back slopes, plant community of lower strata was diverse with different plant life forms. Shade tolerant herbs, such as *C. canadensis*, *C. borealis, L. borealis* and *T. borealis* were abundant, indicating the soil conditions of mature forest and low level of maintenance disturbance. Abundance of bryophytes especially *R. triquitrus* and *H. splendens* in back slope indicated moist substrate in back slopes (Vitt et al. 1988). Abundance of *K.*

angustifolia and *L. groenlandicum* in back slopes also indicated the presence of organic matter that was not disturbed for a long time.

Dominant herbs of the back slope tend to allocate higher biomass to the below ground parts than the above ground parts. The herbs in the back slope grow and regenerate in the partially decomposed duff layer in association with other shrubs and trees. High root-shoot ratio of plants indicates poor site conditions in terms of soil resources, as the plants allocated more energy to their below ground parts to ensure maximum acquisition and storage of soil resources (Tilman 1988). Although the back slope was found to have high moisture content and less compaction, even then this microhabitat is stressed due to insufficient light and nutrients in the duff layer. Restriction of light penetration and exploitation of soil mineral nutrients by the shrubs and trees of the upper strata may create light and nutrient stress in the duff layer of back slopes (Givnish 1982).

Conclusions and Management Implications

Several conclusions can be made from the present studies that have management implications for roadside revegetation. However, further comprehensive studies using similar approach will make significant contribution in developing guidelines for roadside revegetation with native plants.

1) Several naturally occurring native plants with desirable properties have been found to colonize in different roadside microhabitats. Plant species can be selected from these naturally occurring species pool for revegetation of respective roadside microhabitats. For example, despite the poor moisture and organic matter content, several plant species, such as *E. nigrum, J. communis, V. angustifolium, T. repens*, and *A. margaritacea* have been successfully colonized and dominated the side slope.

2) The present study found that *E. nigrum, J. communis, V. angustifolium, T. repens*, and *A. margaritacea* have desirable attributes to reduce soil erosion, ensure traffic visibility and regenerate naturally. These species have many attributes, such as low stature, widespread above and below ground parts, perennial habit and drought and salt tolerant properties, which make them desirables plants for roadside revegetation. Moreover, these species can be propagated vegetatively for large-scale revegetation programme, as they regenerate from rhizomes and adventitious roots from stems.

4) Dominant plants from other microhabitats can also be suggested to revegetate side slope, especially those species with high competitive ability and allelopathic potential to reduce the invasion of exotic species. For example, *K. angustifolia,* one of the dominant plants in the back slope, has high competitive ability and allelopathic property that may reduce invasion of exotic plants in the side slope. Although, the autecological properties of this species have not been studied in the present study, it has potential for side slope revegetation because of its rapid vegetation growth from rhizome and stem based sprouting.

Chapter 2: Revegetation of newly constructed roadside habitats by using native plants

Introduction

The colonization and establishment of natural vegetation in newly constructed roadsides is time consuming. Removal of the topsoil including existing plant communities and use of artificial materials for road construction usually leaves the habitat with a poor biological legacy for subsequent regeneration. Inhospitable substrates of the roadside habitats, associated with chemical inputs from the pavement, automobile exhaust and de-icing salt also hinder colonization and establishment of plant communities (Thompson and Rutter 1986; Spencer and Port 1988). Newly constructed roadsides without vegetation cover are vulnerable to soil erosion, which can pollute surrounding aquatic ecosystems (Forman and Alexander 1998). Newly constructed roadsides also facilitate colonization of undesirable invasive and exotic species, interfering with the management objectives of the conservation areas, such as National Parks (Vitousek 1986; Knops et al. 1995; Greenberg 1997; Mallik 2000).

To avoid the detrimental biophysical effects on the surrounding ecosystem, quick recovery of natural and self-sustained vegetation cover in newly constructed roadsides is necessary (Hobbs and Harris 2001). Although the road engineers provide a grass cover by hydro-seeding after road construction to reduce soil erosion, this method does not have any ecological basis. Moreover, the monoculture of grass may facilitate invasion of exotic plants and aggravate other long-term road effects (Greenberg 1997; Forman and Alexander 1998; Andres and Jorba 2000).

Revegetation of newly constructed roadsides with desirable native plants and using appropriate cultural methods is gaining importance to the restoration ecologists. Several studies were done to understand the problem and prospect of establishing native plants in different habitats (Urbanska et al. 1987; Paschke et al. 2000; Fattorini 2001). However, demonstration of revegetation along newly constructed roadsides by using native plants is rare. Inappropriate selection of planting materials and cultural methods unsuited to inhospitable roadside conditions often cause the failure of roadside revegetation by desirable native plants. Seeding native plants for revegetation of

roadsides may be unpredictable due to their biological limitations, such as poor seed dormancy and viability. Germination and establishment of native plants may also be unpredictable due to the inhospitable substrate properties of roadsides, such as low moisture and nutrient content, high temperature and chemical toxicity (Walker and Powell; DeLeo1999). Removal of seeds before germination by surface run off and wind turbulence may also hinder the seedling establishment in newly constructed roadsides (Walker and Powell 1999). Even the recruited seedlings that overcome all biophysical limitations may face severe competition from invasive plants of roadsides, leading to an uncertain establishment of desirable vegetation (van Epps and McKell 1983; Paschke et al. 2000). Transplantation of seedlings or vegetative cuttings of desirable native plants seems to be an effective method for quick revegetation of inhospitable roadsides, as they can avoid the vulnerable stages of germination and establishment (Urbanska et al. 1987; Paschke et al. 2000; Fattorini 2001).

Mulching, a traditional cultural method, facilitates successful germination of seeds as well as establishment of transplants by providing favourable substrate conditions. The surface-applied mulch can help vegetation establishment by reducing runoff, retaining soil moisture and nutrients and by decreasing soil temperature (Smika and Unger 1986; Ji and Unger 2001). Bark, wood chips, commercially available hay and jute mats and decomposed organic matter serve the purpose of both soil conservation and revegetation in drastically disturbed habitats (Rees 2002).

The cultural manipulations of planting materials as well as the roadside substrate are expected to enhance the native plant establishment in the newly constructed roadsides. In the present study, it is hypothesized that a) stratification of native seeds prior to seeding will enhance germination, and b) mulching treatments will improve seed germination and enhance survival and growth of transplants (seedlings and stem cuttings) in the newly constructed roadside. The objectives of present study were 1) to determine the effect of stratification and mulching on seed germination of selected native plants and 2) to compare different mulching effects on survival and growth of the transplanted seedlings and stem cuttings of selected native plants.

Materials and Methods

Germination experiment

In March 2001, a greenhouse experiment was conducted to determine the effect of stratification (chilling and hydration) treatment on seed germination of six native plants. Seeds of sheep laurel (*Kalmia angustifolia)*, wild iris (*Iris versicolor*), rush *(Juncus effusus*), cotton grass (*Eriophorum vaginatum),* blue bead lily (*Clintonia borealis*) and bunchberry (*Cornus canadensis*) were collected from Terra Nova National Park (TNNP), Newfoundland. Seeds were stored at room temperature until the commencement of germination experiment. Approximately, 0.25 g seeds of *K. angustifolia* (1400 seeds), *J. effusus* (5500 seeds) and *E. vaginatum* (500 seeds) and 0.40 g of *I. versicolor* (20 seeds) were sown in a 10 x 10 x 8 cm deep germination tray filled with sand and peat moss at a 3: 1 ratio. Twenty seeds of *C. borealis* and *C. canadensis* were sown in the same pot and potting medium.

In six germination trays, seeds of each species were soaked and chilled for seven days at 0^0 C in a growth chamber. After the stratification treatment, all the trays (36 trays for six species) were transferred to the greenhouse at 25^0 C. In another batch of germination trays (36 trays for six species), control seeds of the same six species were kept in the greenhouse at 25^0 C. Treated and control germination trays were irrigated with tap water at alternate days for five weeks. The number of emerging seedlings was counted weekly for five consecutive weeks.

Revegetation experiment by seeds and transplants

In June 2001, a field experiment was conducted to compare the effects of hay-mat and organic matter mulch on seed germination of several native plants in the newly constructed roadsides. During the same time, another field experiment was also conducted to compare the effects of the mulching treatments on survival and growth of seedlings and stem cuttings of native plants. The side slope and ditch of newly constructed (one-year-old) roadside sections of TCH in TNNP were selected for the revegetation experiments. The width of the side slope was between 4 and 6 m, with a slope ranging from 30^0 to 35^0. The substrate properties of the ditch were similar to that of

the side slope, except the ditch had high soil moisture content. The ditch was 3 to 4 m wide with a gentle slope.

Hay-mat and organic matter mulch was applied to amend the substrate properties. The hay-mat, also known as erosion control mat was made of dry hay, neatly interwoven by biodegradable jute fibers. Organic matter rich roadside topsoil, which was removed and dumped during road reconstruction 10-15 years ago, was spreaded at 3-5 cm thick layer on the mineral soil of the newly constructed roadside as organic matter mulch.

Planting materials

Seeds of *K. angustifolia*, *I. versicolor*, *E. vaginatum* and *J. effusus*, collected from naturally abundant native plants in TNNP, during late summer of 2000. Collected seeds were air-dried first and stored in an unheated room, until the seeding experiment was conducted in summer 2001. Stem cuttings were propagated from juvenile stems of *J. communis* and *E. nigrum*. These two low-growing evergreen native plants were found to regenerate naturally on the older section of the roadside. Stem cuttings were collected in July 2000 and propagated at Memorial University Botanical Garden. Pieces of juvenile stem (4 cm long) were planted in plastic trays (Root-trainer Spencer-Lemaire, Edmonton, Alberta) filled with peat moss-vermiculite mixture. No special treatment was applied to improve the rooting ability of the stem cuttings. The cuttings were initially covered with plastic paper and irrigated twice a week by tap water but not fertilized. Before transplanting, stem cuttings of *J. communis* and *E. nigrum* attained a mean shoot height of 4 and 6 cm respectively.

Same growing medium was used to raise the seedling of *I. versicolor* and *Carex* sp. in root-trainer. No pre-sowing treatment was applied to the seeds to enhance their germination. Seedlings were irrigated with tap water but not fertilized. Before transplanting, *I. versicolor* and *Carex* sp. attained a mean shoot height of 10 and 11 cm respectively. The stem cuttings and seedlings were transferred from greenhouse to outdoor conditions for two weeks acclimatization before transplanting.

Roadside revegetation experiment layout

In July 2001, each of the experimental plots (26 m x 2 m) was treated with hay-mat or organic matter and replicated three times. One experimental plot was kept control without mulching and also replicated three times. A total of nine experimental plots were assigned randomly to both sides of the newly constructed side slopes parallel to the pavement (Figure 1 a). Within each experimental plot, *K. angustifolia* and *I. versicolor* were seeded in two different sub-plots (2 m x 2 m) and one sub-plot was kept control (without seeding). Sub-plots were randomly assigned and replicated three times within the experimental plot (Figure 1 b). Buffer strips (1 m x 1 m) were kept between the experimental sub-plots to avoid seed mixing of adjacent sub-plots (Figure 1 b). Seeding experiment by *J. effusus* and *E. vaginatum* were conducted in the ditch following the same experimental design. All the seeding experimental plots were irrigated by tap water twice a week for the first month after sowing.

In July 2001, the transplanting experiment was also conducted following the same experimental design as of the seeding experiment, except that the size of experimental plots and sub-plots were 17 m x 1 m and 1 m x 1 m respectively. One-year-old stem cuttings of *E. nigrum* and *J. communis* were transplanted in the newly reconstructed side slopes. A total of 16 stem cuttings of each species were transplanted in each sub-plots at 25 cm x 25 cm spacing. No stem cutting was transplanted in the control sub-plots. Seedlings of *I. versicolor* and *Carex* sp. were transplanted in the ditch treated by hay-mat and organic matter mulches following the same experimental design. These experimental plots were also irrigated regularly by tap water.

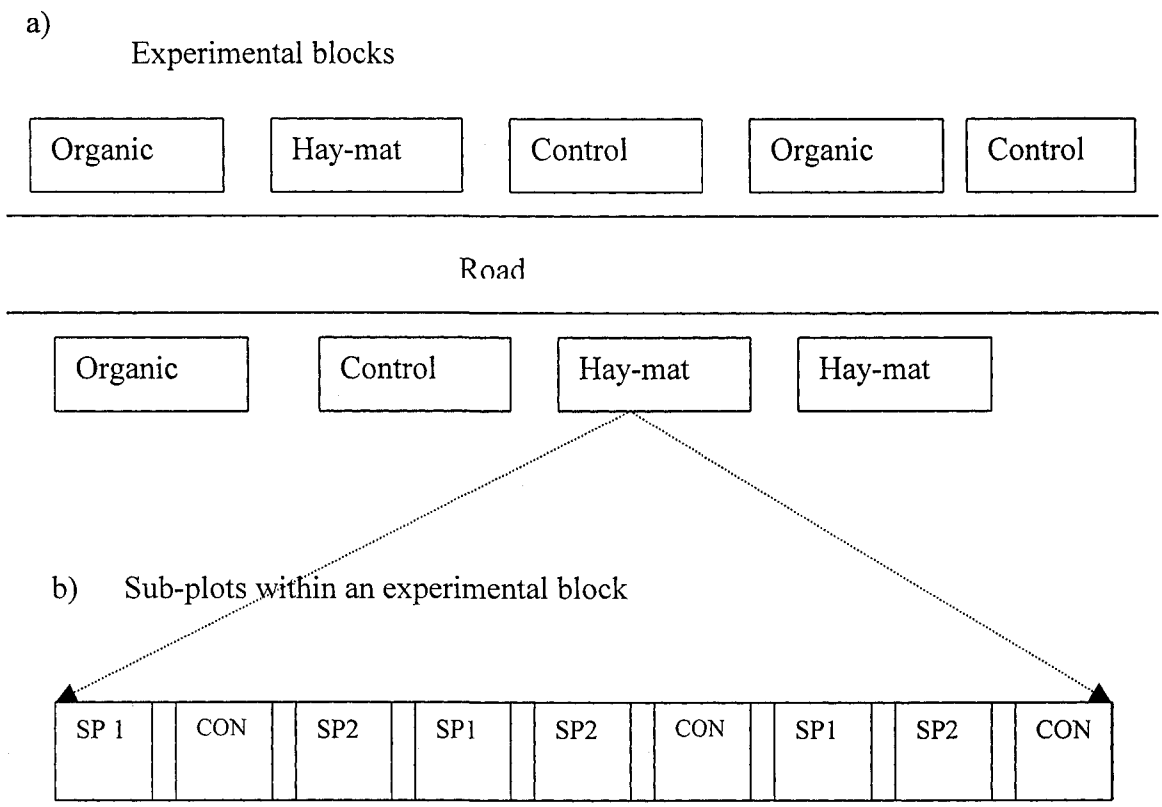


Figure 1. Layout design of seeding and transplanting experiments along the newly constructed roadside habitats of the TCH, a) Layout of the experimental plots that were treated by mulching with either hay-mat or organic matter, Control experimental plots had no mulching treatment b) Layout of sub-plots within an experimental plot, where Sp1, Sp2 represents the sub-plot seeded or transplanted with two species and CON represents the control sub-plots without any seeding or transplanting.

Data collection

Germination data of the greenhouse experiment were recorded by counting seedlings, emerging from the germination tray at a weekly interval during March to April 2001. Dead seedlings were not counted to determine the cumulative percent germination. In June 2002, germination data of the field experiment were recorded by counting emerging seedlings, one year after seeding. At the same time, the percent cover of germinated seedlings was also recorded from 50 cm x 50 cm quadrats, placed randomly in the 2 m x 2 m experimental sub-plots.

In June 2001, the initial shoot length of transplanted stem cuttings and seedlings were taken from eight randomly selected cuttings from each sub-plot. In August 2003, the final shoot length of the stem cuttings and seedlings were also taken from eight randomly selected cuttings from each sub-plot, 15 months after transplanting. A total of 72 stem cuttings and seedlings of each species were selected from each type of mulch treatment for shoot length measurement. The shoot length was determined by measuring the longest shoot from the ground level to the tip. Percent survival was determined by averaging the number of total live transplants found in the sub-plots, 15 months after transplantation. A total of 18 transplants of each species (seedlings and stem cuttings) were excavated from each type of mulching treatment for determining the root-shoot length and dry biomass. The plant samples were dried in oven at 65^0 C until constant weight.

Data analysis

Kruskal-Wallis non-parametric test of significance was applied to compare treatment means of the germination experiment in the greenhouse, as the data were not normally distributed. One-way ANOVA was performed to determine significant treatment differences in survival, shoot length and dry biomass of the transplants. Tukey's HSD *Post Hoc* test of multiple comparisons was performed to compare treatment means. The natural log and square root methods were used to normalize the data, when the transformation was necessary. Kolmogorov-Smirnov (K-S) test of normality and Levenes test of equal variance was performed to ensure that the data followed the assumption of ANOVA.

Results

Greenhouse germination experiment

The stratification treatment significantly enhanced seed germination of four native species when compared to the control treatment. Although significantly higher germination was obtained in the stratified treatments compared to control, germination remained quite low at 2.5 % and 8 % in *J. effusus* and *K. angustifolia* respectively (Figure 2 a, b) and moderate in *E. vaginatum* and *I. versicolor* at 25 % and 50 % respectively (Figure 2 c, d). Control seeds of all the four species experienced either very poor or no germination. Without stratification (control) *J. effusus*, *I. versicolor*, and *K. angustifolia* seeds had low germination at 0.5 %, 6 % and 8 % respectively, while that of *E. vaginatum* did not germinate at all (Figure 2 a, b, c). The stratification treatment enhanced germination of *K. angustifolia* seeds by three weeks. However, at the end of the 4^{th} week, the germination of *K. angustifolia* did not show significant difference between the stratified and control treatment (Figure 2 b).

Revegetation experiment by seeding

Of the seeds of four native plants, only *I. versicolor* germinated successfully in newly constructed the side slope. Germination of *I. versicolor* seed was significantly increased (20 %) in organic matter mulch compared to control. But it was significantly decreased (5 %) in hay-mat mulch compared to control (Figure 3). Cover (%) value of the germinated seedlings form different mulching treatment also showed similar trend of the result of the cumulative (%) germination (Figure 3).

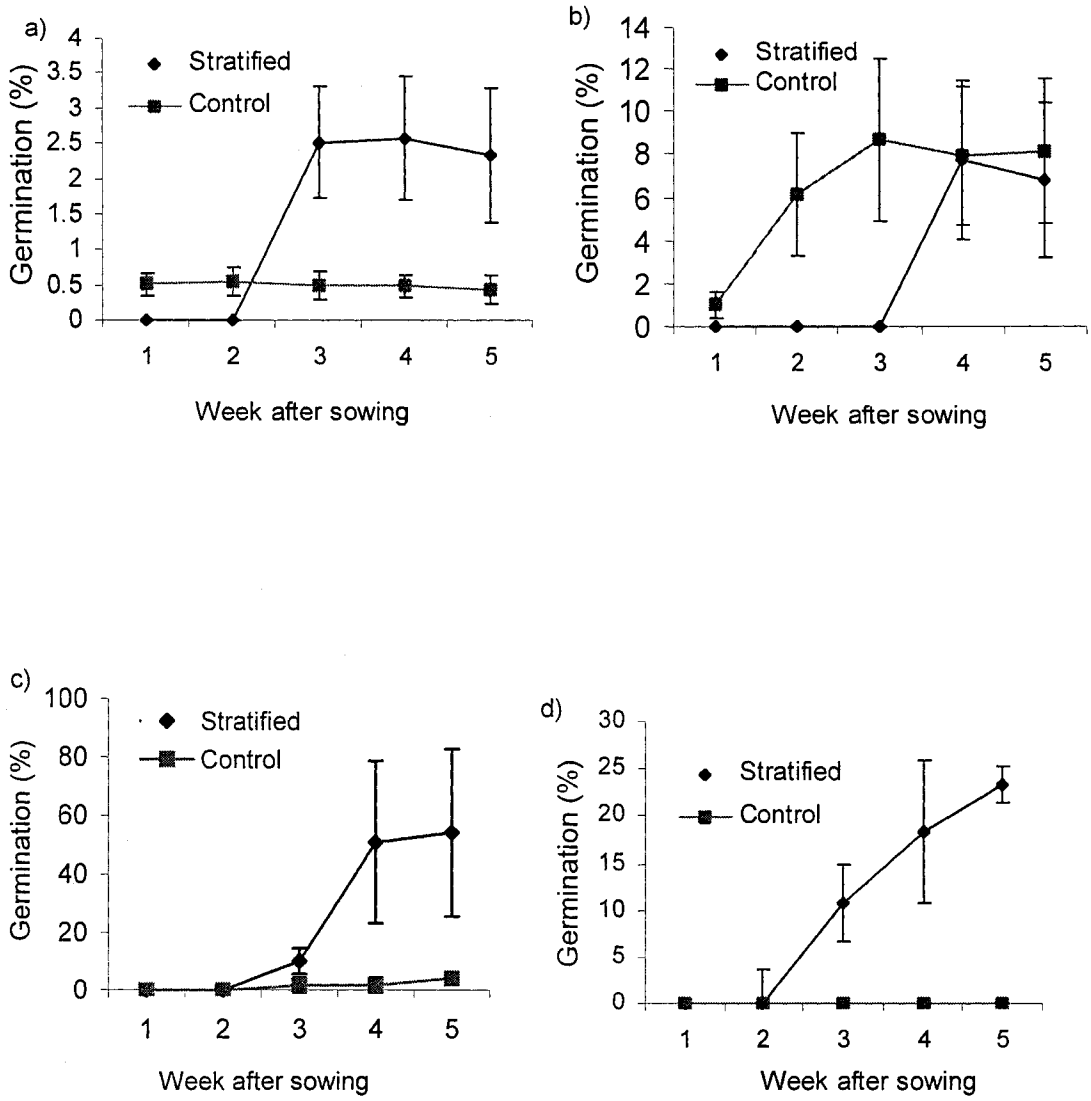


Figure 2. Cumulative germination (%)(Mean ± sd) of stratified (at 0^0C for 7 days) and un-stratified (control) seeds of a) *Juncus effusus* b) *Kalmia angustifolium* c) *Iris versicolor* and d) *Eriophorum vaginatum.* Mean values were recorded from six replicates of each species at a weekly interval for 5 weeks. Significant treatment differences of cumulative germination (%) at every week were determined by the Kruskal-Wallis non-parametric test.

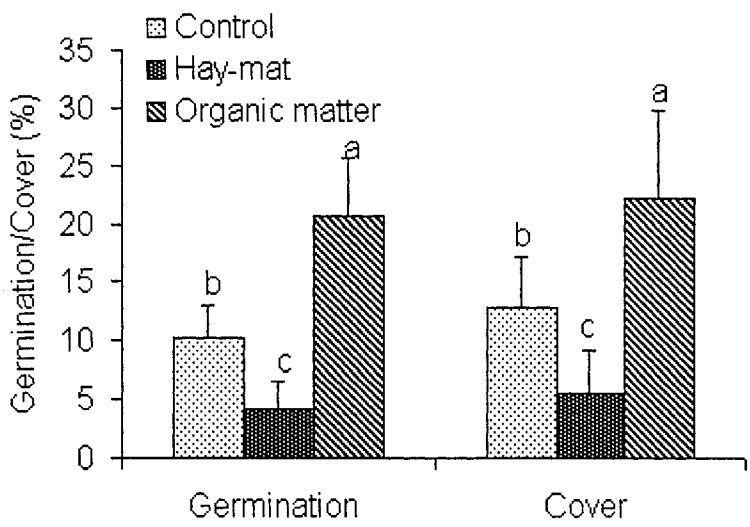


Figure 3. Germination and cover (%) (Mean ± sd; N = 9 sub-plot/treatment) of *Iris versicolor* following one year of seeding at different mulching treatments in newly constructed side slopes of the TCH. Unlike letters in each category indicate significant difference at $P \leq 0.05$, determined by one-way ANOVA and Tukey's HSD test.

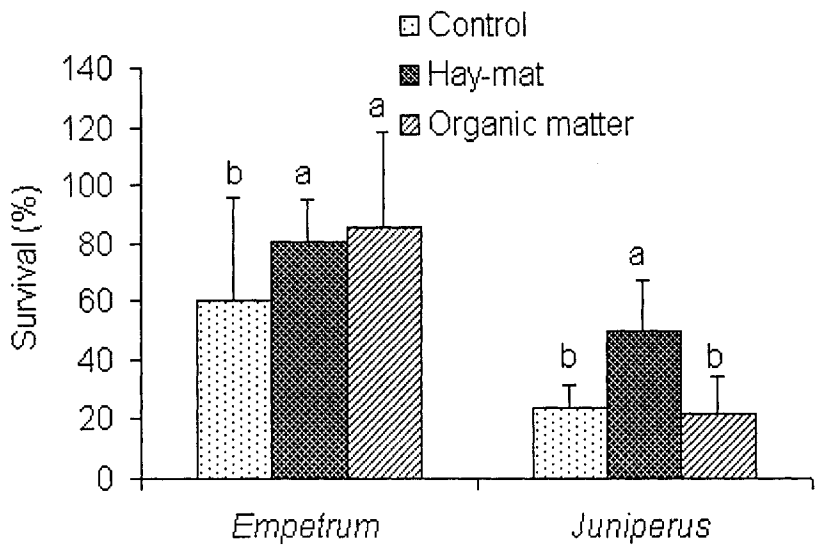
Revegetation by transplants

Survival

Hay-mat and organic matter mulch maintained significantly higher survival of *E. nigrum* and *J. communis* cuttings compared to the control (Figure 4 a). Survival of *E. nigrum* stem cuttings remained similar in both hay-mat and organic matter mulches at 80 % and 78 % respectively, but it was significantly lower in control (60 %)(Figure 4 a). The overall survival of *J. communis* cuttings was low among the mulching treatments, although the hay-mat mulch retained significantly higher survival at 44 % compared to the control. The lowest survival of *J. communis* cuttings was observed in organic matter mulches at 25 % and was similar to the control (Figure 4 a).

Mulching had no significant effect on the survival of the transplanted *I. versicolor* and *Carex* sp. seedlings, which remained quite high between 95 % and 80 % respectively (Figure 4 b).

a)



b)

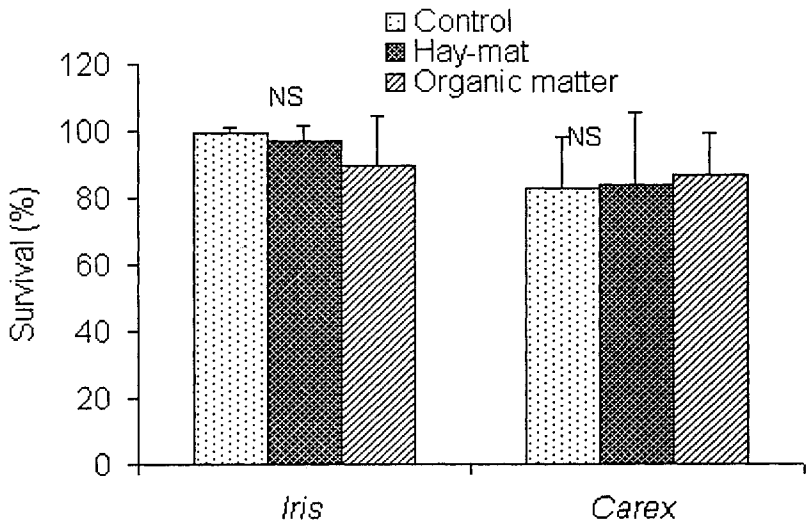


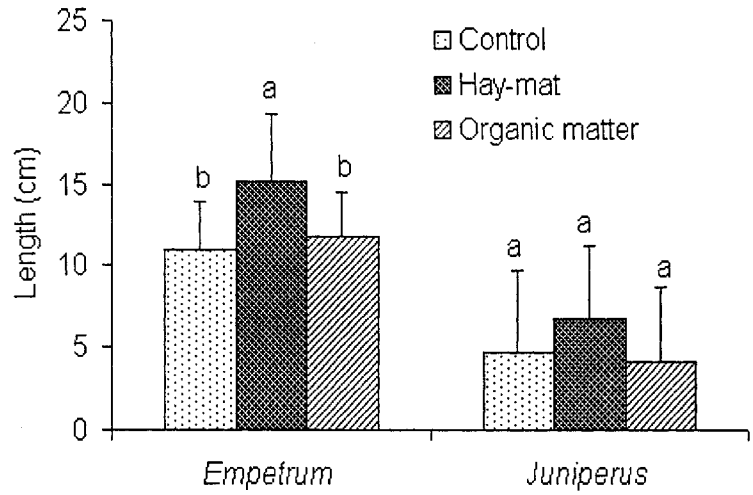
Figure 4. Survival (%) (Mean ± sd; N = 144 cuttings/treatment) of a) *Empetrum nigrum* and *Juniperus communis* stem cuttings and b) *Iris versicolor* and *Carex* sp. seedling after transplanting in hay-mat and organic matter mulch on roadsides of TCH. Unlike letters in each category of species indicate significant treatment differences at $P \leq 0.001$, and NS = not significant, determined by the one-way ANOVA and Tukey's HSD test.

Shoot length

In general, the shoot length of *J. communis* cuttings remained lower than that of *E. nigrum* among all the mulching treatments, 15 months after transplanting (Figure 5 a). During transplanting, the mean initial shoot length of *J. communis* and *E. nigrum* (8 randomly taken cuttings of each species) was attained 4 and 6 cm respectively. Mulching had no significant effect on shoot length of *J. communis* cuttings, but it affected shoot length of *E. nigrum* cuttings (Figure 5 a). Compared to the cuttings in control treatment (no mulching), the shoot length of *E. nigrum* cuttings were significantly higher in hay-mat mulch. But no significant difference was found in shoot length of *E. nigrum* cuttings transplanted in organic matter mulch and control treatment (Figure 5 a). In the hay-mat mulch, shoot length of *E. nigrum* cutting was doubled (100 %) from the initial length, measured during transplanting However, the shoot length of *E. nigrum* stem cuttings transplanted in the organic matter and control mulch was increased only by 50 % (Figure 5 a).

Mulching was less effective for the shoot growth of *I. versicolor* and *Carex* sp. seedlings, as the transplants in control treatment were taller than that of other mulching treatments (Figure 5 b). In control, the shoot length of the *I. versicolor* and *Carex* sp. seedling were increased by 100 % and 70 % respectively from the initial length, whereas in organic matter mulch, it was increased only by 25 % for both species. Although the shoot length of *I. versicolor* was higher in control, the value did not vary significantly from the seedlings in the hay-mat mulch. But *I. versicolor* seedlings in hay-mat were significantly taller than that in the organic matter mulch (Figure 5 b). *Carex* sp. seedlings in the control were the tallest but they were not significantly different from other mulching treatments (Figure 5 b).

a)



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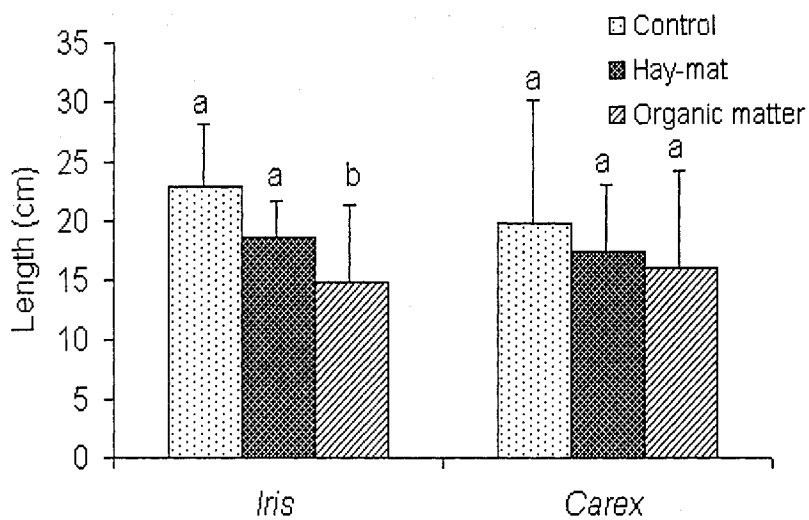
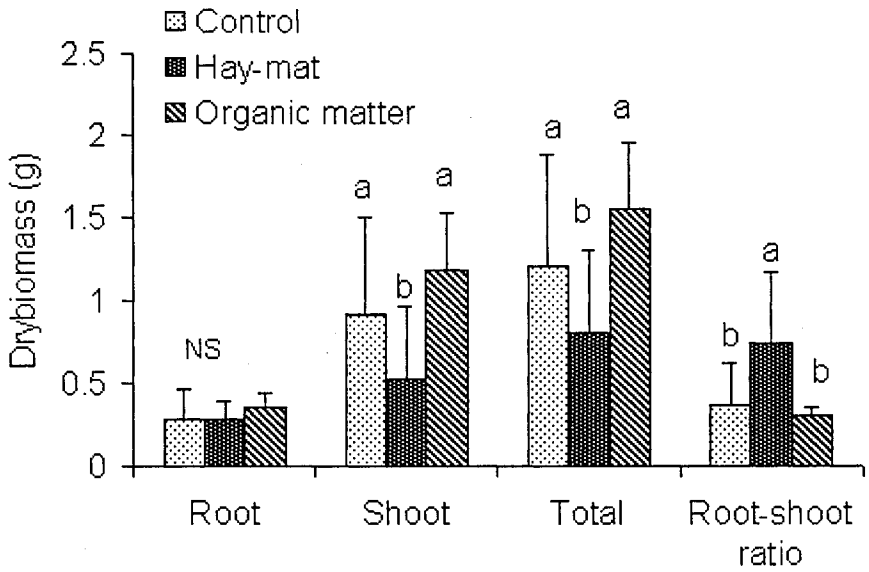


Figure 5. Shoot length (Mean ± sd; N=72 cuttings per treatment) of a) *Empetrum nigrum* and *Juniperus communis* stem cuttings and b) *Iris versicolor* and *Carex* sp. seedlings after transplanting in hay-mat and organic matter mulch on roadsides of TCH. Unlike letters in each category of species indicate significant treatment differences at $P \leq 0.001$, determined by the one-way ANOVA and Tukey's HSD test.

Biomass allocation of transplants

In general, *E. nigrum* and *J. communis* allocated approximately two-thirds of the total plant dry biomass to the above ground parts of the stem cutting in different mulching treatments. However, the total biomass of the *E. nigrum* cuttings was higher than that of the *J. communis* among all the mulch treatments (Figure 6 a, b). Stem cuttings of *E. nigrum*, transplanted in the organic matter mulch produced the highest amount of total plant biomass (root and shoot) (Figure 6 a). In organic matter mulch, total plant biomass of *E. nigrum* cuttings was significantly higher by 40 % than that in hay-mat mulch (Figure 6 a). However, there was no significant difference in total plant biomass of the *E. nigrum* cutting, transplanted in the organic matter mulch and control (Figure 6 a). The mulching treatment did not affect the biomass allocation of the *J. communis* cuttings, as the highest amount of total plant biomass was found in the control treatment (Figure 6 b). Although the total plant biomass of the *J. communis* cuttings, transplanted in organic matter mulch was not significantly lower than that of the control treatment. However, total plant biomass of *J. communis* cuttings, transplanted in hay-mat mulch was significantly lower by 30 % than that of the control (Figure 6 b). Mulching treatment did not significantly affect the root biomass of the cuttings of both species; however, the shoot biomass of the cuttings was significantly affected by the mulching treatment. Shoot biomass of the cuttings of both species was significantly higher in control and organic matter mulch treatment (Figure 6 a, b). Root-shoot ratio of the cuttings of both species was significantly higher in hay-mat mulch than that of the control and organic matter mulch (Figure 6 a, b).

a)



b)

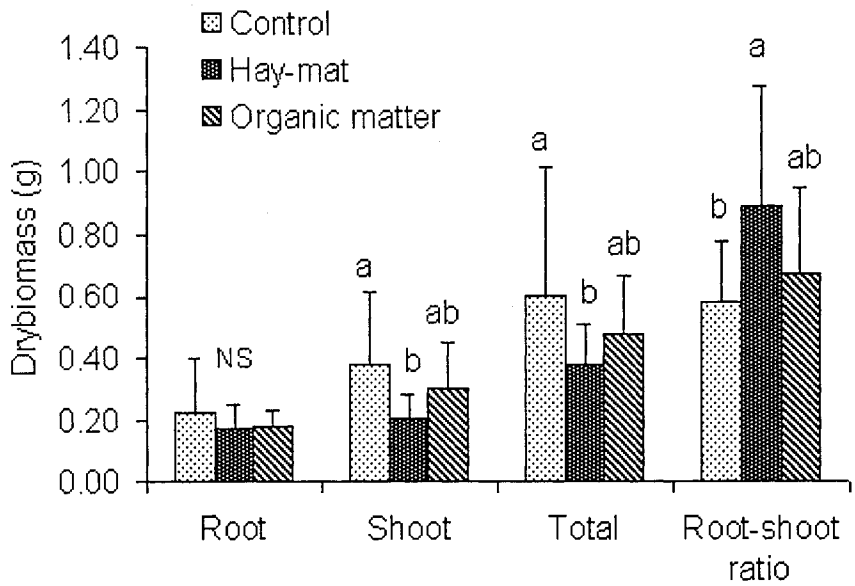
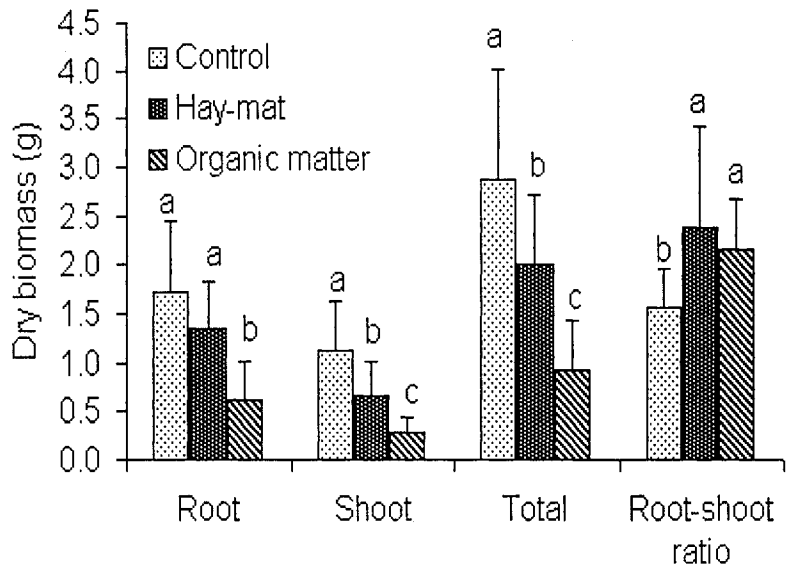


Figure 6. Dry biomass (g) (Mean ± sd; N=18 cuttings/treatment) of a) *Empetrum nigrum* and b) *Juniperus communis* stem cuttings after transplanting in hay-mat and organic matter mulch on roadside of TCH. Unlike letters in each category of parameters indicate significant differences at $P \leq 0.05$ and NS = not significant, determined by the one-way ANOVA and Tukey's HSD test.

In general, seedlings of *I. versicolor* and *Carex* sp. had similar biomass allocation pattern with more biomass allocation to roots than shoots (Figure 7 a, b). Total biomass allocation (root and shoot) of the seedlings transplanted in organic matter mulch was significantly lower than the seedlings transplanted in hay-mat much and control. The total biomass of the *I. versicolor* was significantly lower by 30 % and 70 % in hay-mat and organic mulches respectively, when compared to the control treatments (Figure 7 a). The total biomass of *Carex* sp. seedlings in the hay-mat mulch and control treatment was similar but it was significantly lower in organic matter mulch by 45 % from that of the control treatment (Figure 7 b).

a)



b)

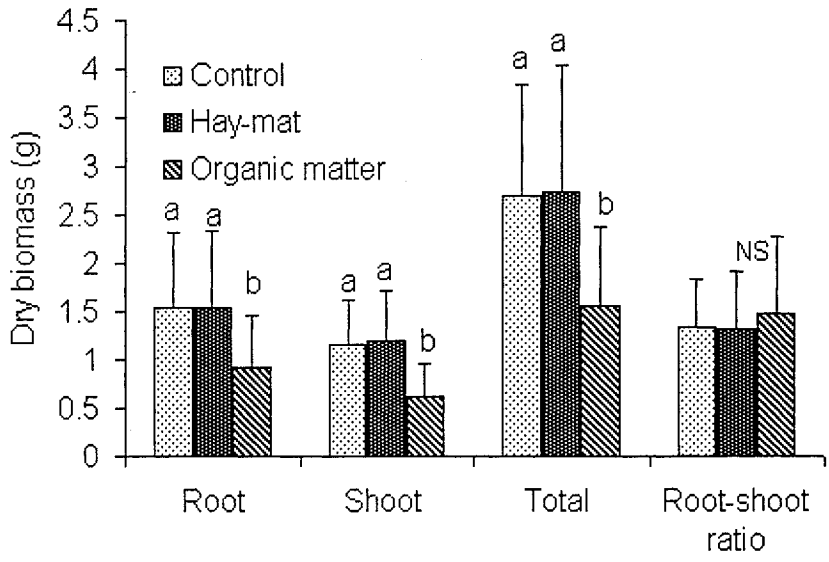


Figure 7. Dry biomass (g) (Mean ± sd; N=18 cuttings/treatment) of a) *Iris versicolor* and b) *Carex* sp. seedling after transplanting in hay-mat and organic matter mulch on roadside of TCH. Unlike letters in each category of parameters indicate significant differences at $P \leq 0.05$ and NS = not significant, determined by the one-way ANOVA and Tukey's HSD test.

Discussion

Germination success in greenhouse and field conditions

Germination of all the four native species was notably increased by stratification treatment in the greenhouse experiment. However, when seeded in the field conditions, only *I. versicolo*r seeds germinated successfully after one winter. Stratification is known to stimulate germination of many native plants in the northern ecosystem (Grime 1979). However, poor seed germination under field conditions may be attributed to improper stratification. Germination experiment showed that the native seeds require both cold and moist conditions simultaneously in order to break the seed dormancy. In field conditions, those seeds might be cold treated during the winter, but they might not get enough moisture due to dryness of roadside substrates.

The size and weight of the seeds may be an important factor for successful germination in the exposed habitat, where surface run off and wind turbulence interfere with the settling of seeds on soil surface (Keddy 1986). The seeds of *I. versicolor* were larger and heavier than those of other native plants, used in this study. Small seeds of *E. vaginatum, J. effusus* and *K. angustifolia* can easily be washed away by the surface run off and wind turbulence from the newly constructed roadsides. On the other hand, seeds of *I. versicolor* might be less vulnerable to surface run off allowing them to settle easily in the newly constructed roadsides. Moreover, the coarse roadside substrates with high mineral fractions might be unable to hold the tiny seeds. The pattern of soil particles and seed size and weight play critical role for successful settlement of seeds on the seedbed followed by a successful germination, especially in exposed and uneven habitats (Keddy 1986).

Germination of *I. versicolor* seeds was significantly affected by the mulching treatments. High seed germination in organic matter mulch can be attributed to more favourable moisture and temperature conditions than that of the hay-mat and control treatment. The cold treated seeds may require abrupt change of temperature to break the dormancy for successful germination that was reveled by the greenhouse experiment in this study. Seeds buried under the organic matter mulch might have had sufficient heat, moisture and nutrients for successful germination.

Revegetation by stem cuttings

Stem cuttings of *E. nigrum* survived and established better than those of *J. communis* in all the mulching treatments. Naturally, *E. nigrum* colonizes in extremely inhospitable soil conditions with poor moisture and nutrient contents, especially on sandy and rocky substrate. *E. nigrum* has an excellent capacity to survive in a wide range of ecological conditions from dry to wet (Bell and Tallis 1958). The survival after prolonged snow cover is another ecological advantage of the *E. nigrum*, reported by the same authors. Moreover, the fine root systems with ericoid mycorrhizae may make the plant capable of withstanding drought and nutrient poor conditions (Read 1983). By contrast, although *J. communis* is a naturally abundant plant in nutrient poor exposed habitats, it may not be as stress tolerant as *E. nigrum*, because of their coarse roots and absence of stress adapted ericoid mycorrhizae (Houle and Babeux 1994). Poor root development coupled with frost heaving in early spring may also reduce the survival of *J. communis* cuttings.

Mulching treatments significantly affected the survival and establishment of stem cuttings. Hay-mat mulch significantly increased the survival of *E. nigrum* and *J. communis* cuttings. Stem cuttings of both species survived well in hay-mat mulch, 15 months after transplanting. Soil erosion due to strong turbulence of surface run off is reported to be a critical factor for the early survival and establishment of transplants, especially in the exposed habitat with mineral substrate and steep slopes (Hansen 1989; DeLeo 1999). Hay-mat mulch reduces turbulence of surface run off and hence protects the newly transplanted cuttings from washout. Hay-mat mulch also retains soil moisture by reducing evaporation that may ensure available moisture to the transplants (Grantz et al. 1998).

In organic matter mulch, stem cuttings of *E. nigrum* survived better than *J. communis*. Organic matter mulch may supply nutrients and retain moistures leading to a successful establishment of *E. nigrum* cuttings. But the poor survival *J. communis* cutting in organic matter mulch was difficult to explain. It is possible that the organic matter mulch may contain salt and lead, as it was collected form roadside topsoil. This pollution in organic matter mulch might have affected the survival and growth of *J. communis* cuttings by damaging the juvenile roots (Power et al. 1978; Thompson and Rutter 1986;

Spencer and Port 1988). The salt and lead toxicity might not affect cuttings of *E. nigrum*, as the species had stress tolerating characteristics (Monni et al. 2001, 2002). Further investigations are needed to determine tolerance levels of *E. nigrum* and *J. communis* cuttings to different chemical toxicities.

Shoots of *E. nigrum* and *J. communis* cuttings grew better in hay-mat mulch than that of the cuttings transplanted in organic matter mulch. On the other hand, the cuttings of *E. nigrum* and *J. communis* in hay-mat mulch produced lower biomass when compared to the cuttings transplanted in organic matter mulch. Hay-mat mulch retains more soil moisture and reduces disturbance from surface run off, which might have induced shoot growth of the cuttings. Poor shoot growth but high biomass allocation pattern of the cutting, transplanted in organic matter mulch is difficult to explain. The newly transplanted cuttings may be highly sensitive to moisture and nutrients status of a particular habitat. Organic matter mulch probably supplies enough nutrients and moisture, which may affect the cuttings to invest more biomass in lateral increment for improving physical strength of stems, instead of allocating shoot development to capture light energies. Plants grown in stress tend to be more conservative in investing their limited energy for effective use of further growth and development (Grime 1979). Low root-shoot ratio of the stem cuttings of *E. nigrum* and *J. communis* in the organic matter and control may also suggest higher allocation of energy to lateral shoot increment for increasing physical strength against the turbulence of surface run off. In a contrary, higher root-shoot ratio of the cuttings in the hay-mat mulch may suggest that cuttings allocated more energy in root elongation in search of moisture and nutrients (Tilman 1988). As hay-mat mulch protects the cuttings from the surface run off turbulence, they tend to be more conservative for unnecessary energy investment in to the shoot for lateral increment (Orians and Solbrig 1977; Bloom et al. 1985).

Revegetation experiment by transplanted seedlings

Mulching did not have any significant affect on the survival of *I. versicolor* and *Carex* sp. seedling. Revegetation experiment by transplants revealed that seedlings of *I. versicolor* and *Carex* sp. established and grew successfully without mulching treatment, 15 months after transplanting. These species may be naturally resilient in the severely

disturbed and stressed habitats because of their successful vegetative reproduction from below ground rhizomes and fibrous root systems (Robertson 1984; Gleason and Cronquist 1991, Kron and Stewart 1994). Seedling of *I. versicolor* and *Carex* sp. allocated more biomass to the below ground parts than that of above ground parts in order to develop rhizomes and strong fibrous roots. Fibrous root systems of *I. versicolor* and *Carex* sp. increase water absorption and help to bind soil particles. Thus, seedlings of these two species may reduce soil erosion of newly constructed roadsides. Seedlings transplanted in the organic matter mulch grew lower shoot length than that of the hay-mat mulch and the control. The organic matter mulch was expected to increase the productivity of seedlings by providing nutrition. However, the organic matter did not increase the growth of seedlings. It is possible that chemical toxicity in the organic mulch might have induced growth inhibition in the transplanted seedlings.

Conclusions and Management implications

Although there is enough room for further research to improve cultural methods, several conclusions can be made from the seeding and transplanting experiment along the newly constructed roadsides.

1) Revegetation by seeding of native plants is realistic if the seeds are properly treated by stratification before sowing in the field conditions. Native plants with larger and heaver seeds are recommended for roadside revegetation, as larger seeds are likely to settle better than those with tiny seeds vulnerable to washout by surface run off. Although the organic matter mulch treatment enhanced seed germination of *I. versicolor*, it should be used cautiously, as it may enhance the invasion of exotic plants from the buried seeds.

2) Both seedlings and stem cuttings can be used to revegetate newly constructed roadsides without any mulching treatment. Hay-mat mulching can be used only where the side slopes are steep and vulnerable to surface run off. Use of roadside organic matter is not recommended for roadside revegetation, because it may contain toxic elements affecting survival and growth of the juvenile transplants.

3) More experiments are suggested to determine the most appropriate cultural methods for vegetative propagation of other desirable plants in the greenhouse experiment followed by roadside planting.

General Discussion

Recognizing the need for developing roadside vegetation cover by native plants, this study was aimed to examine the naturally occurring roadside plant communities and to determine appropriate cultural methods to revegetate newly constructed roadsides.

The floristic composition was significantly different among the roadside microhabitats tested by the MRPP. In this study, although the floristic differences with respect microhabitats was expected, the reason behind such floristic differences was important for understanding the roadside plant communities. The roadside substrate properties such as bulk density, moisture content, depth of organic matter and pH were significantly different among the four microhabitats. The hypothesis of floristic difference with respect substrate properties across roadside microhabitats was convincing, as CCA clearly showed ecological relationships between plant abundance and substrate properties. Moreover, a number of indicator species of different life forms was abundant and frequent in their respective microhabitats, indicating the preferential dominance of those plants to particular sets of environmental conditions. Cilliers and Bredenkamp (2000) found similar results, as they recognized a gradient of plant community compositions in relation to substrate properties across the microhabitats in roadside verges of Potchefstroom, South Africa. Roadside maintenance activities also play important role on floristic differences across the roadside habitats (Parr and Way 1988). In the present study, descriptive categorical variables of maintenance disturbance were used to asses their influence on plant community composition. However, a stronger argument can be made by further quantitative and experimental studies on this aspect.

Beside the floristic differences across the roadside habitats, the dominant plants of different microhabitats appeared to have different life history strategies. In this study, the above and below ground plant architectural characteristics and biomass allocation patterns of the dominant plants of a certain microhabitat appeared to be similar, but were significantly different with respect to other microhabitats. Plant colonization and establishment depends on their successful reproduction and dominance in response to a stress-disturbance continuum (Grime 1979; Parish and Bazzaz 1982). Plants maintain a trade off between above and below ground biomass allocation pattern for their

reproduction and dominance that enable them to colonize and establish in a habitat (Chemielewski and Ringius 1987). The biomass allocation pattern of the dominant roadside plants suggested that these plants might employ similar strategies of allocating above and below ground biomass to colonize and establish in their respective microhabitats in response to a stress-disturbance continuum. In this study, a stronger inference could have been made about the role of biomass allocation pattern on plant colonization and establishment, if more sample plants were examined from each microhabitat. Therefore, further study with sufficient representative samples from each microhabitat will provide more convincing evidences to support this trend identified in this study.

Knowledge of the above and below ground architectural characteristics and biomass allocation can be applied in selecting native plants for mitigating soil erosion in newly constructed roadsides (Mallik and Rashid 1993). Side slopes are the most vulnerable roadside microhabitats subject to soil erosion. Most of the undesirable native and exotic species colonize on side slopes, which interfere with roadside management and conservation issues of the national parks. This study found that the naturally occurring dominant native plants on the side slope, such as *E. nigrum, J. communis, V. angustifolium* and *A. margaritacea,* have wide spread shoot and root systems to protect side slopes from soil erosion. The low profile but wide spread structure of these plants may ensure traffic visibility and better roadside vegetation management. Further investigation is necessary to determine the full potential of roadside plants to mitigate road effects.

Revegetation of newly constructed roadsides is often difficult, because of the biological limitation of planting materials and inhospitable substrate properties of roadside habitats. The results from greenhouse and filed experiments suggested that both cold and moist conditions were prerequisites for successful germination of those native plants. Seed of native plants is a useful planting material, if they were properly chilled and soaked before sowing in newly constructed roadsides. In addition, regular watering of the treated seeds would have enhanced the seed germination in field conditions.

Mulching was expected to enhance the seed germination of native plants by providing favourable conditions to the seedbed and protecting the seeds from surface run

off. However, only *I. versicolor* germinated successfully in the newly constructed roadside habitats after one winter. Inadequate stratification and removal of seeds from side slopes and ditches by surface run off were recognized as two major reasons for unsuccessful germination of the other native plants. The success of germination also depends on the size and weight of the seeds, especially in the exposed habitats with steep slope, where the seeds are vulnerable to surface runoff (Keddy 1986; Hansen 1989; DeLeo 1999). Despite the mulching, the tiny seeds of other species were probably washed away by the rain or snowmelt water from the seedbeds. *K. angustifolia* was one of the selected native plants germinated successfully in control environment without stratification treatment and was expected to germinate in the field conditions. However, despite the mulching, *K. angustifolia* did not germinate at all, might be due to tiny size of the seeds that was washed away from the seedbeds. In contrast, seeds of *I. versicolor* were large enough to adhere to the seedbed as well as had the thick seed coat to absorb enough moisture to germinate even without mulching. Probably, seeds of *I. versicolor* were chilled during the long winter and hydrated by snowmelt water during the spring that could lead to a successful germination.

Recently revegetation by transplants is gaining importance to restoration ecologists to avoid the uncertainties related with the germination of native seeds, especially in the inhospitable substrate conditions. The revegetation experiments by transplants revealed that the seedlings of *I. versicolor* and *Carex* sp. established and grew successfully without mulching treatments, 15 months after transplanting. These two species may be naturally resilient in the severely disturbed and stressed habitats because of their successful vegetative reproduction from the below ground rhizomes and fibrous root systems (Robertson 1974; Gleason and Cronquist 1991). Seedlings of both the species allocated higher amount of biomass to the below ground part that indicated strong rhizomatous growth with profuse fibrous roots. The success of seedling survival and growth without mulching suggested them economically and logistically feasible planting materials for revegetation of newly constructed roadsides. However, rapid plant cover development to protect the exposed roadside soil from surface runoff and exotic colonization is an important attribute to consider in selecting planting materials for revegetation.

Revegetation by stem cuttings seems to be an effective method for those species that have difficulties to propagate by seeds due to the biological limitations. In this study, stem cuttings of *E. nigrum* survived and grew better than that of *J. communis* treated with mulching treatments. Hay-mat mulching significantly increased the survival and growth of the cuttings of both species. Better survival and growth of *E. nigrum* cuttings may be attributed by the stress tolerating properties of *E. nigrum* that can withstand the inhospitable substrate properties of the newly constructed roadsides. The existing literatures regarding the autecology of both species suggest that *E. nigrum* can establish better than *J. communis* in unfavorable conditions (Bell and Tallis 1958; Read 1983; Houle and Babeux 1993; Monni et al. 2001, 2002). Planting these species with well developed rooting from stem cutting can solve this problem. These may require more time in greenhouse to develop healthy root systems from the cuttings before planting on the roadsides. Stronger root systems and early planting may also help to reduce their mortality due to frost heaving during early spring. However, further experiments are needed to compare the stress tolerating abilities of these two species before suggesting mass propagation of stem cuttings for revegetation of newly constructed roadside habitats.

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Appendix-1

Mean percentage cover value of roadside plants of six life forms in different microhabitats along the 10-15 years old sections of TCH. The mean value was determined from 37, 41, 26 and 60 quadrates located in shoulder, side slope, ditch and back slope respectively along 34 randomly laid out transects perpendicular to the pavement. Species with cover value less than 10 % was not included.

Species	Microhabitat			
	Shoulder	Side slope	Ditch	Back slope
Trees				
Abies balsamea (L.) Mill.	0	0.3	1.2	1
Larix laricina (Du Roi) K. Koch	0	1.4	0.8	0.4
Picea mariana (Mill.) B.S.P	0	7.9	4.5	6.3
Betula pumila L.	0	0.9	5	3.4
Populus tremuloides Michx.	0	2.1	0.8	4.5
Shrubs				
Alnus crispa (Ait.) Pursh	0.1	0.2	1.2	0.9
Alnus rugosa (Du Roi) Spreng.	0	2.4	3.3	2.8
Empetrum nigrum L.	3.4	11.6	0	0
Juniperus communis L.	0	13.4	4.9	2.9
Kalmia angustifolia L.	0	5.5	11	15.2
Ledum groenlandicum Oeder	0	0.6	1.1	2.5
Spiraea latifolia (Ait.) Borkh.	0	0.3	2.1	0.2
Sorbus americana (Marsh)	0	0	0.4	0.2
Vaccinium angustifolium Aiton.	0	3.6	1	1.4
Herbs				
Achillea millefolium L.	0.5	0.6	0.4	0.3
Anaphalis margaritacea (L.) Benth. & Hook	1	2.3	0.6	0
Aster spp.	0	0.1	1	0.6
Chrysanthemum sp.	0	0	0.7	0.3
Clintonia borealis (Aiton) Raf.	0	0	0.6	1.8
Cornus canadensis L.	0	0.8	3.7	12.7
Epilobium angustifolium L.	0	2.1	1.3	0.6
Fragaria vesca L.	0	1	2.1	0.8
Gaultheria hispidula L.	0	0.5	0.1	1.5
Hieracium spp.	0.5	0.3	0.3	0.3

Iris versicolor L.	0	0	0.8	0.3
Leontodon automnalis L.	0.4	0.8	0.4	0.2
Linnaea borealis L.	0	0.8	0.3	2.9
Maianthemum canadense Desf.	0	0	0.2	0.9
Plantago major L.	1.3	0	0	0
Rubus pubescens Raf.	0	4.1	1.8	4.3
Solidigo spp.	0.4	0.9	0.8	1
Trientalis borealis Raf.	0	0	0.2	0.1
Trifolium repens L.	0.3	2.1	0	0.7
Vaccinium vitis-idea L.	0.2	0.6	0.3	0.1
Viola sp.	0	0	1.2	0.8
Grasses	4.2	7.9	15.6	8.6
Bryophytes				
Equisetum spp.	0	0	0	0.9
Hylocomium splendens (Hedw.) BSG.	0	0	8.8	11.5
Polytrichum piliferum Hedw.	0	0.2	4.8	1.5
Ptilium crista-castrensis (Hedw.) De Not	0	0.7	4.2	1.4
Rhytidiadelphus triquitrus (Hedw.) Warnst.	0	19	5.6	15.7
Pleurozium schreberi (Brid.) Mitt	0	3.4	2.7	0.7
Sphagum girgensohnii Russ.	0	0.7	6.2	2.4
Sphagum spp.	0	0	4.2	0.3
Lichens				
Cladina arbuscula (Wallr.) Hale & Culb.	0	1.2	3.5	2.9
Cladina mitis (Sandst.) Hale & Culb.	0.3	0.3	0	0.2
Cladina rangiferina (L.) Harm.	0	0	0.2	0.3

Appendix-2

Total number, length and location of transects laid randomly across the adjacent forest types observed along the TCH in TNNP, as well as the number of quadrats located at four different roadside microhabitats with brief physical properties.

Transects	Length	No. Quadrats				Forest type
	(m)	Shoulder	Side slope	Ditch	Back slope	
1	25	1	2	1	2	Kalmia barren
2	20	1	1	0	2	Spruce-fir
3	35	1	1	1	3	Black spruce
4	28	1	1	1	1	Black spruce
5	33	2	1	1	2	Larch
6	30	1	2	1	1	Black spruce
7	23	1	1	0	1	Spruce-fir
8	35	1	1	2	2	Black spruce
9	30	1	1	1	2	Black spruce
10	30	1	1	1	2	Black spruce
11	38	1	2	1	2	Spruce-fir
12	21	1	1	0	2	Black spruce
14	34	1	2	1	2	Black spruce
15	40	1	1	1	3	Spruce-fir
16	33	2	1	1	2	Kalmia barren
17	26	1	1	0	2	Spruce-larch
18	31	2	1	1	2	Softwood scrub
19	29	1	1	1	1	Spruce-fir
20	33	1	2	0	2	Spruce-larch
21	31	1	1	1	1	Black spruce
22	27	1	1	0	1	Black spruce
23	22	1	1	0	1	Black spruce
24	29	1	1	1	2	Mixed wood
25	30	1	1	1	1	Black spruce
26	35	1	2	1	2	Spruce-larch
27	27	1	1	0	2	Black spruce
28	36	1	2	1	2	Black spruce
29	38	1	1	1	2	Black spruce
30	40	1	1	1	2	Black spruce
31	35	1	1	1	2	Black spruce
32	35	1	1	1	2	Black spruce
33	40	2	1	1	2	Black spruce
34	38	1	2	1	2	Black spruce
quadrats		37	41	26	60	
Width		2 m	2-6 m	2-4 m	4-10 m	
Soil texture		Gravel	Sand + Silt	Sand + Silt + Clay	Sand + silt	
Moisture		Dry	Dry to moist	Wet to moist	Moist	